EO/US
PCT/IL98/00476

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Assistant Commissioner for Patents
United States Patent and Trademark Office
Box PCT
Washington, D.C.20231
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing: 06 April 2000 (06.04.00)	
International application No.: PCT/IL98/00476	Applicant's or agent's file reference: 001/00575
International filing date: 28 September 1998 (28.09.98)	Priority date:
Applicant: IDDAN, Gavriel, J. et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International preliminary Examining Authority on:

07 September 1999 (07.09.99)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was
[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer: J. Zahra Telephone No.: (41-22) 338.83.38

Form PCT/IB/331 (July 1992)

3197646

PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

FENSTER & COMPANY PATENT
ATTORNEYS, LTD
P.O.Box 10256
Petach Tikva 49002
ISRAEL

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

Date of mailing *(day/month/year)*	20.12.2000
Applicant's or agent's file reference 001/00575	**IMPORTANT NOTIFICATION**

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/IL98/00476	28/09/1998	28/09/1998

Applicant
3DV SYSTEMS, LTD. et al.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

   The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

   Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

   For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	SCHALINATUS, D Tel.+49 89 2399-8242

Form PCT/IPEA/416 (July 1992)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
001/00575		
International application No. PCT/IL98/00476	International filing date (day/month/year) 28/09/1998	Priority date (day/month/year) 28/09/1998
International Patent Classification (IPC) or national classification and IPC H04N3/15		
Applicant 3DV SYSTEMS, LTD. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 7 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 7 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☒ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☒ Certain defects in the international application
   VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
07/09/1999	20.12.2000
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer McGrath, S Telephone No. +49 89 2399 8961

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/IL98/00476

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:

Description, pages:

1-22	as originally filed				

Claims, No.:

1-40	as received on	09/10/2000	with letter of	05/10/2000	

Drawings, sheets:

1/7-7/7	as originally filed				

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).

   ☐ the language of publication of the international application (under Rule 48.3(b)).

   ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   ☐ contained in the international application in written form.

   ☐ filed together with the international application in computer readable form.

   ☐ furnished subsequently to this Authority in written form.

   ☐ furnished subsequently to this Authority in computer readable form.

   ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   ☐ the description, pages:

   ☒ the claims, Nos.: 41-47

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

IV. Lack of unity of invention

1. In response to the invitation to restrict or pay additional fees the applicant has:

   ☐ restricted the claims.

   ☐ paid additional fees.

   ☐ paid additional fees under protest.

   ☐ neither restricted nor paid additional fees.

2. ☒ This Authority found that the requirement of unity of invention is not complied and chose, according to Rule 68.1, not to invite the applicant to restrict or pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rules 13.1, 13.2 and 13.3 is

   ☐ complied with.

   ☒ not complied with for the following reasons:
   see separate sheet

4. Consequently, the following parts of the international application were the subject of international preliminary examination in establishing this report:

   ☒ all parts.

   ☐ the parts relating to claims Nos. .

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-40
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-36
	No:	Claims	37-40

Industrial applicability (IA)	Yes:	Claims	1-40
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

Concerning Point IV - Lack of Unity

Unity is considered to be lacking in the claims.

The separate inventions/groups of inventions are:

Claims 1-6 - "3D-camera" with modulation/gating for distance measurement;
Claims 36-40 - photosurface/methods for removing effects of background light and dark currents.

Claims 7-35 are hybrid claims having combinations of the above features.

They are not so linked as to form a single general inventive concept (Rule 13.1 PCT) since the only the common link is a photosurface which is known per se. See in this connection any of the documents cited in the International Search Report.

Concerning Point V - Reasoned Statement

1. The following document, cited in the International Search Report, is mentioned in this report:

   D4: US-A-5 488 415

   D4 discloses circuits in an autofocus camera including a photoelectric cell receiving light transmitted from the camera itself for the purposes of measuring the distance to a an object to be imaged. D4 includes some circuitry to remove background light to improve the detection of the reflected light coming from the camera's own light source. However, D4 makes no mention of how the distance can be measured.

2. From the applicants' own prior art mentioned in the description it is known to detect distance by gating or modulating the light source and then gating or modulating the reflected light.

3. The subject-matter of claim 1 combines elements of all the above prior art but differs yet again in that the second gating/modulation is applied to the current from a light sensitive element.
   None of the available prior art documents alone or in combination discloses or suggests such subject-matter.
   The subject-matter of claim 1 would therefore appear to meet the requirements of Articles 33(2) and 33(3) PCT.

4. Claims 2-35 contain modifications of the inventive idea embodied in claim 1 and would also appear to meet the requirements of Articles 33(2) and 33(3) PCT.

5. Claim 36 concerns a photosurface having an arrangement of a feedback capacitor and switches which allow the flow of current into the capacitor from the light sensitive element to be reversed.
   None of the available prior art documents alone or in combination discloses or suggests the specific circuit arrangement of claim 36.
   The subject-matter of claim 36 would therefore appear to meet the requirements of Articles 33(2) and 33(3) PCT.

6. The subject-matter of claim 37 does not meet the requirements of Article 33(3) and Rule 65(1)(2) PCT since it does not involve an inventive step.

   See D4, col. 12-13. Whilst D4 does not expressly mention a pulse of light it is considered obvious that after the light is turned on (see col. 13, lines 24-32) it is not required to be on indefinitely, thus the skilled person will recognize that the light should be turned off after the gating of the photodiode is completed. Thus a pulse is obtained.
   In D4 the subtraction of the background light signal from the combined background plus the light from the light source signal is carried out while the latter signal is received. However the wording of claim 37 is broad enough to read on to D4 on this point.

7. The following dependent claims do not appear to contain any additional features which, in combination with the features of any claim to which they refer, involve an

inventive step:

claims 38-40 - see D4 and the knowledge of the skilled person.

Concerning Point VII - Certain Defects

1. The requirements of Rule 6.3(b) PCT are not met since the independent claims are not properly cast in the two part form, according to which those features which in combination are part of the prior art are placed in the preamble.

2. The requirements of Rule 5.1(a)(iii) PCT are not met since the opening part of the description is not in agreement with the claims.

3. The requirements of Rule 5.1(a)(ii) & (iii) PCT are not met since the background art, useful for understanding the invention, eg the documents mentioned above, have not been acknowledged in the description and the technical problems and any advantageous effects have not yet been stated in comparison to this background art.

4. The phrase "herein incorporated by reference" and similar wordings - see page 2, passim - does not meet the requirements of Rule 9.1(iv) PCT.

5. The requirements of Rule 6.2(b) PCT are not met since reference signs are not used in the claims. It is considered that the presence of such signs would significantly aid the understanding of the claims.

●TENT COOPERATION TREATY ●

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INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 001/00575	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/IL 98/ 00476	International filing date *(day/month/year)* 28/09/1998	(Earliest) Priority Date *(day/month/year)*
Applicant 3DV SYSTEMS, LTD. et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 2 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.
   [ ] filed together with the international application in computer readable form.
   [ ] furnished subsequently to this Authority in written form.
   [ ] furnished subsequently to this Authority in computer readble form.
   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [ ] the text is approved as submitted by the applicant.
   [X] the text has been established by this Authority to read as follows:

   DISTANCE MEASUREMENT WITH A CAMERA

5. With regard to the **abstract,**

   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 3

   [X] as suggested by the applicant.
   [ ] because the applicant failed to suggest a figure.
   [ ] because this figure better characterizes the invention.

   [ ] None of the figures.

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From the INTERNATIONAL SEARCHING AUTHORITY

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT OR THE DECLARATION

(PCT Rule 44.1)

To:
FENSTER & COMPANY PATENT ATTORNEYS, LTD
P.O.Box 10256
Petach Tikva 49002
ISRAEL

RECEIVED
07-06-1999
FENSTER & Co.

Date of mailing (day/month/year) 25/05/1999	
Applicant's or agent's file reference 001/00575	**FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/IL 98/00476	International filing date (day/month/year) 28/09/1998
Applicant 3DV SYSTEMS, LTD. et al.	

1. [X] The applicant is hereby notified that the International Search Report has been established and is transmitted herewith.

Filing of amendments and statement under Article 19:
The applicant is entitled, if he so wishes, to amend the claims of the International Application (see Rule 46):

When? The time limit for filing such amendments is normally 2 months from the date of transmittal of the International Search Report; however, for more details, see the notes on the accompanying sheet.

Where? Directly to the International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland
Fascimile No.: (41-22) 740.14.35

For more detailed instructions, see the notes on the accompanying sheet.

2. [ ] The applicant is hereby notified that no International Search Report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. [ ] **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

[ ] the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

[ ] no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Further action(s):** The applicant is reminded of the following:

Shortly after **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90*bis*.1 and 90*bis*.3, respectively, before the completion of the technical preparations for international publication.

Within **19 months** from the priority date, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase until 30 months from the priority date (in some Offices even later).

Within **20 months** from the priority date, the applicant must perform the prescribed acts for entry into the national phase before all designated Offices which have not been elected in the demand or in a later election within 19 months from the priority date or could not be elected because they are not bound by Chapter II.

Name and mailing address of the International Searching Authority	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Shantisaroop Pherai

Form PCT/ISA/220 (July 1998)

NOTES TO FORM PCT/ISA/220

These Notes are intended to give the basic instructions concerning the filing of amendments under article 19. The Notes are based on the requirements of the Patent Cooperation Treaty, the Regulations and the Administrative Instructions under that Treaty. In case of discrepancy between these Notes and those requirements, the latter are applicable. For more detailed information, see also the PCT Applicant's Guide, a publication of WIPO.

In these Notes, "Article", "Rule", and "Section" refer to theprovisions of the PCT, the PCT Regulations and the PCT Administrative Instructions respectively.

INSTRUCTIONS CONCERNING AMENDMENTS UNDER ARTICLE 19

The applicant has, after having received the international search report, one opportunity to amend the claims of the international application. It should however be emphasized that, since all parts of the international application (claims, description and drawings) may be amended during the international preliminary examination procedure, there is usually no need to file amendments of the claims under Article 19 except where, e.g. the applicant wants the latter to be published for the purposes of provisional protection or has another reason for amending the claims before international pbulication. Furthermore, it should be emphasized that provisional protection is available in some States only.

What parts of the international application may be amended?

Under Article 19, only the claims may be amended.

During the international phase, the claims may also be amended (or further amended) under Article 34 before the International Preliminary Examining Authority. The description and drawings may only be amended under Article 34 before the International Examining Authority.

Upon entry into the national phase, all parts of the international application may be amended under Article 28 or, where applicable, Article 41.

When? Within 2 months from the date of transmittal of the international search report or 16 months from the priority date, whichever time limit expires later. It should be noted, however, that the amendments will be considered as having been received on time if they are received by the International Bureau after the expiration of the applicable time limit but before the completion of the technical preparations for international publication (Rule 46.1).

Where not to file the amendments?

The amendments may only be filed with the International Bureau and not with the receiving Office or the International Searching Authority (Rule 46.2).

Where a demand for international preliminary examination has been/is filed, see below.

How? Either by cancelling one or more entire claims, by adding one or more new claims or by amending the text of one or more of the claims as filed.

A replacement sheet must be submitted for each sheet of the claims which, on account of an amendment or amendments, differs from the sheet originally filed.

All the claims appearing on a replacement sheet must be numbered in Arabic numerals. Where a claim is cancelled, no renumbering of the other claims is required. In all cases where claims are renumbered, they must be renumbered consecutively (Administrative Instructions, Section 205(b)).

The amendments must be made in the language in which the international application is to be published.

What documents must/may accompany the amendments?

Letter (Section 205(b)):

The amendments must be submitted with a letter.

The letter will not be published with the international application and the amended claims. It should not be confused with the "Statement under Article 19(1)" (see below, under "Statement under Article 19(1)").

The letter must be in English or French, at the choice of the applicant. However, if the language of the international application is English, the letter must be in English; if the language of the international application is French, the letter must be in French.

The letter must indicate the differences between the claims as filed and the claims as amended. It must, in particular, indicate, in connection with each claim appearing in the international application (it being understood that identical indications concerning several claims may be grouped), whether

(i) the claim is unchanged;

(ii) the claim is cancelled;

(iii) the claim is new;

(iv) the claim replaces one or more claims as filed;

(v) the claim is the result of the division of a claim as filed.

The following examples illustrate the manner in which amendments must be explained in the accompanying letter:

1. [Where originally there were 48 claims and after amendment of some claims there are 51]: "Claims 1 to 29, 31, 32, 34, 35, 37 to 48 replaced by amended claims bearing the same numbers; claims 30, 33 and 36 unchanged; new claims 49 to 51 added."
2. [Where originally there were 15 claims and after amendment of all claims there are 11]: "Claims 1 to 15 replaced by amended claims 1 to 11."
3. [Where originally there were 14 claims and the amendments consist in cancelling some claims and in adding new claims]: "Claims 1 to 6 and 14 unchanged; claims 7 to 13 cancelled; new claims 15, 16 and 17 added." or "Claims 7 to 13 cancelled; new claims 15, 16 and 17 added; all other claims unchanged."
4. [Where various kinds of amendments are made]: "Claims 1-10 unchanged; claims 11 to 13, 18 and 19 cancelled; claims 14, 15 and 16 replaced by amended claim 14; claim 17 subdivided into amended claims 15, 16 and 17; new claims 20 and 21 added."

"Statement under article 19(1)" (Rule 46.4)

The amendments may be accompanied by a statement explaining the amendments and indicating any impact that such amendments might have on the description and the drawings (which cannot be amended under Article 19(1)).

The statement will be published with the international application and the amended claims.

It must be in the language in which the international appplication is to be published.

It must be brief, not exceeding 500 words if in English or if translated into English.

It should not be confused with and does not replace the letter indicating the differences between the claims as filed and as amended. It must be filed on a separate sheet and must be identified as such by a heading, preferably by using the words "Statement under Article 19(1)."

It may not contain any disparaging comments on the international search report or the relevance of citations contained in that report. Reference to citations, relevant to a given claim, contained in the international search report may be made only in connection with an amendment of that claim.

Consequence if a demand for international preliminary examination has already been filed

If, at the time of filing any amendments under Article 19, a demand for international preliminary examination has already been submitted, the applicant must preferably, at the same time of filing the amendments with the International Bureau, also file a copy of such amendments with the International Preliminary Examining Authority (see Rule 62.2(a), first sentence).

Consequence with regard to translation of the international application for entry into the national phase

The applicant's attention is drawn to the fact that, where upon entry into the national phase, a translation of the claims as amended under Article 19 may have to be furnished to the designated/elected Offices, instead of, or in addition to, the translation of the claims as filed.

For further details on the requirements of each designated/elected Office, see Volume II of the PCT Applicant's Guide.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
001/00575		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/IL 98/00476	28/09/1998	
Applicant		
3DV SYSTEMS, LTD. et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 2 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.

   [ ] filed together with the international application in computer readable form.

   [ ] furnished subsequently to this Authority in written form.

   [ ] furnished subsequently to this Authority in computer readble form.

   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).
3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [ ] the text is approved as submitted by the applicant.

   [X] the text has been established by this Authority to read as follows:

   DISTANCE MEASUREMENT WITH A CAMERA

5. With regard to the **abstract,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 3

   [X] as suggested by the applicant.

   [ ] because the applicant failed to suggest a figure.

   [ ] because this figure better characterizes the invention.

   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 98/00476

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04N3/15 G01S17/08 H04N5/217

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04N G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 28558 A (FOSSUM ERIC R ;CALIFORNIA INST OF TECHN (US)) 7 August 1997 see page 7, line 3 - page 8, line 8 see page 11, line 13 - page 15, line 20; figure 3A ---	1-15,44
X	US 5 329 312 A (BOISVERT DAVID M ET AL) 12 July 1994 see figure 2 ---	1-15
X	US 5 488 415 A (UNO MASAYUKI) 30 January 1996 see figure 18 see column 12, line 11 - line 63; figures 13,14 -----	1-7,16, 17,19,20

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 May 1999	25/05/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	De Paepe, W

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IL 98/00476

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9728558 A	07-08-1997	AU 1833597 A	22-08-1997
		AU 1835397 A	22-08-1997
		EP 0878007 A	18-11-1998
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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 001/00575	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/IL98/00476	International filing date *(day/month/year)* 28/09/1998	Priority date *(day/month/year)* 28/09/1998
International Patent Classification (IPC) or national classification and IPC H04N3/15		
Applicant 3DV SYSTEMS, LTD. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 7 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 7 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☒ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☒ Certain defects in the international application
   VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
07/09/1999	20.12.2000
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer McGrath, S Telephone No. +49 89 2399 8961

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/IL98/00476

I. Basis of the report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:
Description, pages:

1-22	as originally filed			

Claims, No.:

1-40	as received on	09/10/2000	with letter of	05/10/2000

Drawings, sheets:

1/7-7/7	as originally filed			

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   - ☐ the description, pages:
   - ☒ the claims, Nos.: 41-47

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

IV. Lack of unity of invention

1. In response to the invitation to restrict or pay additional fees the applicant has:

   ☐ restricted the claims.

   ☐ paid additional fees.

   ☐ paid additional fees under protest.

   ☐ neither restricted nor paid additional fees.

2. ☒ This Authority found that the requirement of unity of invention is not complied and chose, according to Rule 68.1, not to invite the applicant to restrict or pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rules 13.1, 13.2 and 13.3 is

   ☐ complied with.

   ☒ not complied with for the following reasons:
   see separate sheet

4. Consequently, the following parts of the international application were the subject of international preliminary examination in establishing this report:

   ☒ all parts.

   ☐ the parts relating to claims Nos. .

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-40
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-36
	No:	Claims	37-40

Industrial applicability (IA)	Yes:	Claims	1-40
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

Concerning Point IV - Lack of Unity

Unity is considered to be lacking in the claims.

The separate inventions/groups of inventions are:

Claims 1-6 - "3D-camera" with modulation/gating for distance measurement;
Claims 36-40 - photosurface/methods for removing effects of background light and dark currents.

Claims 7-35 are hybrid claims having combinations of the above features.

They are not so linked as to form a single general inventive concept (Rule 13.1 PCT) since the only the common link is a photosurface which is known per se. See in this connection any of the documents cited in the International Search Report.

Concerning Point V - Reasoned Statement

1. The following document, cited in the International Search Report, is mentioned in this report:

   D4: US-A-5 488 415

   D4 discloses circuits in an autofocus camera including a photoelectric cell receiving light transmitted from the camera itself for the purposes of measuring the distance to a an object to be imaged. D4 includes some circuitry to remove background light to improve the detection of the reflected light coming from the camera's own light source. However, D4 makes no mention of how the distance can be measured.

2. From the applicants' own prior art mentioned in the description it is known to detect distance by gating or modulating the light source and then gating or modulating the reflected light.

3. The subject-matter of claim 1 combines elements of all the above prior art but differs yet again in that the second gating/modulation is applied to the current from a light sensitive element.
   None of the available prior art documents alone or in combination discloses or suggests such subject-matter.
   The subject-matter of claim 1 would therefore appear to meet the requirements of Articles 33(2) and 33(3) PCT.

4. Claims 2-35 contain modifications of the inventive idea embodied in claim 1 and would also appear to meet the requirements of Articles 33(2) and 33(3) PCT.

5. Claim 36 concerns a photosurface having an arrangement of a feedback capacitor and switches which allow the flow of current into the capacitor from the light sensitive element to be reversed.
   None of the available prior art documents alone or in combination discloses or suggests the specific circuit arrangement of claim 36.
   The subject-matter of claim 36 would therefore appear to meet the requirements of Articles 33(2) and 33(3) PCT.

6. The subject-matter of claim 37 does not meet the requirements of Article 33(3) and Rule 65(1)(2) PCT since it does not involve an inventive step.

   See D4, col. 12-13. Whilst D4 does not expressly mention a pulse of light it is considered obvious that after the light is turned on (see col. 13, lines 24-32) it is not required to be on indefinitely, thus the skilled person will recognize that the light should be turned off after the gating of the photodiode is completed. Thus a pulse is obtained.
   In D4 the subtraction of the background light signal from the combined background plus the light from the light source signal is carried out while the latter signal is received. However the wording of claim 37 is broad enough to read on to D4 on this point.

7. The following dependent claims do not appear to contain any additional features which, in combination with the features of any claim to which they refer, involve an

inventive step:

claims 38-40 - see D4 and the knowledge of the skilled person.

Concerning Point VII - Certain Defects

1. The requirements of Rule 6.3(b) PCT are not met since the independent claims are not properly cast in the two part form, according to which those features which in combination are part of the prior art are placed in the preamble.

2. The requirements of Rule 5.1(a)(iii) PCT are not met since the opening part of the description is not in agreement with the claims.

3. The requirements of Rule 5.1(a)(ii) & (iii) PCT are not met since the background art, useful for understanding the invention, eg the documents mentioned above, have not been acknowledged in the description and the technical problems and any advantageous effects have not yet been stated in comparison to this background art.

4. The phrase "herein incorporated by reference" and similar wordings - see page 2, passim - does not meet the requirements of Rule 9.1(iv) PCT.

5. The requirements of Rule 6.2(b) PCT are not met since reference signs are not used in the claims. It is considered that the presence of such signs would significantly aid the understanding of the claims.

CLAIMS

1. A 3D camera for determining distances to regions in a scene comprising:

a photosurface having a plurality of pixels each of which comprises a circuit having a single light sensitive element that provides a current responsive to light incident thereon and wherein the circuit is controllable to modulate or gate the current;

a light source;

a controller that controls the light source to illuminate the scene with gated or modulated light and wherein the controller gates or modulates current from the light sensitive element of a pixel in the photosurface responsive to the time dependence of the gating or modulation of the light and determines a distance to a region imaged on the pixel responsive to the gated or modulated current.

2. A 3D camera according to claim 1 wherein the circuit comprises:

at least one amplifier, having an input and an output;

a feedback capacitor separate from the light sensitive element connected between the input and output of each of the at least one amplifier; and

at least one controllable connection through which current flows from the light sensitive element into the input of the at least one amplifier.

3. A 3D camera according to claim 2 wherein the amplifier is an operational amplifier.

4. A 3D camera according to claim 2 or claim 3 wherein the circuit comprises at least one data buss and wherein the circuit comprises at least one address switch that connects a data buss of the at least one data buss to an output of one of the at least one amplifiers, either directly or via another switch.

5. A 3D camera according to any of claims 2-4 wherein the at least one controllable connection comprises at least one gate switch and the controller opens and closes the at least one gate switch to gate the pixel on and off and determines a distance to a region imaged on the pixel responsive to an amount of charge integrated on the feedback capacitor of the at least one amplifier during times at which the pixel is gated on.

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6. A 3D camera according to claim 5 wherein the at least one gate switch comprises a single gate switch that connects the light sensitive element to one amplifier.

7. A 3D camera according to claim 6 wherein the capacitor is connected to the at least one amplifier by a plurality of connection switches such that:

for a first combination of open and closed connection switches a first terminal of the capacitor is connected to the input of the amplifier and a second terminal of the capacitor is connected to the output of the amplifier; and

for a second combination of open and closed connection switches the first terminal of the capacitor is connected to the output of the amplifier and the second terminal of the capacitor is connected to the input of the amplifier.

8. A 3D camera according to claim 7 wherein the controller controls the light source to illuminate the scene with a plurality of light pulses, each having a pulse width and wherein the controller gates pixels in the photosurface on or off at times responsive to times at which light pulses of the plurality of light pulses are radiated.

9. A 3D camera according to claim 8 wherein the controller gates a pixel on for a first gate period following each light pulse in the plurality of light pulses and wherein during the first gate period the controller controls the connection switches according to the first combination and current from the pixel's light sensitive element responsive to background light and light from the radiated light pulse reflected by a region imaged by the pixel plus dark current is integrated on the capacitor and increases voltage across the capacitor.

10. A gated 3D camera according to claim 9 wherein the controller gates the pixel on for a second gate period following each light pulse in the plurality of light pulses and wherein during the second gate period light from the light pulse reflected by the region does not reach the pixel and the controller controls the connection switches according to the second combination so that dark current and current from the pixel's light sensitive element responsive to background light is integrated on the capacitor and decreases voltage across the capacitor.

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11. A 3D camera according to claim 5 wherein the at least one amplifier comprises first and second amplifiers having first and second feedback capacitors respectively and the at least one gate switch comprises first and second gate switches, the first gate switch connecting the light sensitive element to the input of the first amplifier and the second gate switch connecting the light sensitive element to the input of the second amplifier.

12. A 3D camera according to claim 11 wherein the at least one address switch comprises first and second address switches, the first address switch connecting the output of the first amplifier to the data buss and the second address switch connecting the output of the second differential amplifier to the data buss.

13. A 3D camera according to claim 11 wherein the circuit additionally comprises a differential amplifier having positive and negative inputs and an output, wherein the output of the first differential amplifier is connected to the positive input of the differential amplifier, the output of the second differential amplifier is connected to the negative input of the differential amplifier and wherein the output of the differential amplifier is connected by the at least one address switch to the data buss.

14. A 3D camera according to any of claims 11-13 wherein the controller controls the light source to illuminate the scene with a plurality of light pulses, each having a pulse width, and wherein the controller gates pixels in the photosurface on or off at times responsive to times at which light pulses of the plurality of light pulses are radiated.

15. A 3D camera according to claim 14 wherein the controller is operative to:

gate pixels on for a first gate period after a first time lapse following each radiated light pulse of a first plurality of radiated light pulses such that current from the light sensitive element is integrated by the first capacitor; and

gate pixels on for a second gate period after a second time lapse following each radiated light pulse of a second plurality of radiated light pulses such that current from the light sensitive element is integrated by the second capacitor.

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16. A 3D camera according to claim 15 wherein the mid points of first and second gate periods are delayed with respect to the radiated light pulses that they respectively follow by the same amount of time.

17. A 3D camera according to claim 15 or claim 16 wherein the duration of the first gate period is substantially equal to the pulse width of the radiated light pulses.

18. A 3D camera according to any of claims 15-17 wherein the duration of the second gate is greater than or equal to three times the pulse width.

19. A 3D camera according to claim 15 wherein the first time lapse is such that light reflected by a region in the scene from the light pulse reaches a pixel on which the region is imaged during the first gate period, and current from the pixel's light sensitive element responsive to background light, light reflected from the radiated light pulse by the region plus dark current is integrated on the first capacitor.

20. A 3D camera according to any of claims 14-19 wherein the second time lapse is such that light reflected by a region in the scene from the light pulse does not reach the light sensitive element during the second gate period and current from the pixel's light sensitive element responsive to background light plus dark current is integrated on the second integrator.

21. A 3D camera according to any of claims 10, 15, 16, 19 or 20 wherein the duration of the first gate and the duration of the second gate are controlled to be substantially equal.

22. A 3D camera according to any of claims 10, 17, 18, 19-21 wherein the duration of the first and second gates is substantially equal to the pulse width of the radiated light pulses.

23. A 3D camera according to any of claims 5-22 wherein the circuit comprises a reset switch connected to the light sensitive element and wherein when the reset switch is closed, voltage across the light sensitive element is set to a predetermined magnitude.

24. A 3D camera according to claim 23 wherein before the controller gates a pixel on, the controller closes and opens the reset switch of the pixel at least once so that voltage across the light sensitive element is the same each time the pixel is gated on.

25. A 3D camera according to any of claims 5-24 wherein the controller gates at least one pixel in the photosurface independently of other pixels in the photosurface.

26. A 3D camera according to claims 25 wherein pixels in the photosurface are grouped into different pixel groups and pixels in a same pixel group are gated on and off by the controller simultaneously and wherein each pixel group is controlled independently of other pixel groups.

27. A 3D camera according to any of claims 1-6 wherein the controller controls the light source to illuminate the scene with a plurality of light pulses, each having a pulse width, and wherein the controller gates pixels in the photosurface on or off at times coordinated with times at which light pulses of the plurality of light pulses are radiated.

28. A 3D camera according to any of claims 2-4 wherein the at least one controllable connection comprises at least one modulator.

29. A 3D camera according to claim 28 wherein the at least one modulator comprises one modulator that connects the light sensitive element to the input of one amplifier.

30. A 3D camera according to claim 28 or claim 29 wherein the controller controls the at least one modulator to modulate the current from the light sensitive element harmonically.

31. A 3D camera according to claim 28 or claim 29 wherein the at least one modulator is controllable to modulate the current from the light sensitive element pseudo randomly.

32. A 3D camera according to claim 30 wherein the modulated light is harmonically modulated.

33. A 3D camera according to claim 32 wherein the modulated light and the current are modulated at a same frequency of modulation.

34. A 3D camera according to claim 33 wherein the modulation of the light and the current are in phase.

35. A 3D camera according to claim 28 wherein current from the light sensitive element of at least two pixels is modulated at different frequencies.

36. A photosurface comprising a plurality of light sensitive pixels, wherein each pixel of the plurality of pixels comprises an electronic circuit, each of the circuits comprising:

a light sensitive element that provides a current responsive to light incident thereon;

at least one amplifier, having an input and an output;

a feedback capacitor having first and second terminals connected respectively to the input and output of the at least one amplifier by a plurality of switches, which switches are controllable to reverse the connections of the capacitor such that the second and first terminals are connected respectively to the input and output of the at least one amplifier respectively; and

at least one additional switch that connects the light sensitive element to the input of the amplifier, wherein when the additional switch is closed, current provided by the light sensitive element flows into the amplifier input.

37. A method of generating a signal responsive to light reflected by an object from a light pulse radiated by a light source, wherein the signal is corrected for effects of background light and dark current, the method comprising:

sensing the reflected light with a gated sensor that is gated on for a first gate period at a first time determined responsive to a time at which the light pulse is radiated so that at least some of the reflected light from the light pulse is incident on the sensor to generate a first signal having a first value;

gating the sensor on for a second gate period at a second time determined responsive to the time at which the light pulse is radiated so that during the second gate period light from the light source is not incident on the sensor to generate a second signal having a second value; and

subtracting the second value from the first value to form a corrected value.

38. A method according to claim 37 wherein the first gate is such that only a portion of the reflected light incident on the sensor is used to generate the signal having the first value.

39. A method according to claim 36 wherein the first gate is such that substantially all of the reflected light incident on the sensor is used to generate the signal having the first value.

40. A method for normalizing a signal generated responsive to light reflected by an object from gated light incident on the object and for removing the effects of background light and dark current from the signal, the method comprising:

providing a first value generated in accordance with claim 38 or claim 39;
providing a second value generated in accordance with claim 39; and
normalizing the first value using the second value.

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REPLACED BY ART 34 AMDT

CLAIMS

1. A photosurface comprising a plurality of light sensitive pixels, wherein each pixel of the plurality of pixels comprises an electronic circuit, each of the circuits comprising:

a single light sensitive element that provides a current responsive to light incident thereon;

at least one charge accumulator separate from the light sensitive element; and

at least one variable connection through which current flows from the light sensitive element into the integrator.

2. A photosurface according to claim 1 wherein the charge is accumulated on a capacitor.

3. A photosurface according to claim 1 or claim 2 wherein the at least one charge accumulator comprises at least one amplifier, having an input and an output, the at least one capacitor being connected as a feedback capacitor of the amplifier, and wherein the at least one variable connection connects the light sensitive element to the input of the amplifier.

4. A photosurface according to claim 3 wherein the amplifier is an operational amplifier.

5. A photosurface according to claim 3 or claim 4 comprising at least one data buss and wherein the circuit comprises at least one address switch, which connects a data buss to an output of one of the at least one amplifiers, either directly or via another switch.

6. A photosurface according to any of claims 3-5 wherein the at least one variable connection comprises at least one gate switch.

7. A photosurface according to claim 6 wherein the at least one capacitor comprises a single capacitor and the at least one gate switch comprises a single gate switch.

8. A photosurface according to claim 6 wherein:

the at least one capacitor comprises first and second capacitors connected as feedback capacitors respectively to first and second amplifiers to form first and second integrators; and

the at least one gate switch comprises first and second gate switches, the first gate switch connecting the light sensitive element to the input of the first amplifier and the second gate switch connecting the light sensitive element to the input of the second amplifier.

9. A photosurface according to claim 8 wherein the at least one address switch comprises first and second address switches, the first address switch connecting the output of the first amplifier to the data buss and the second address switch connecting the output of the second differential amplifier to the data buss.

10. A photosurface according to claim 8 comprising a differential amplifier having positive and negative inputs and an output, wherein the output of the first differential amplifier is connected to the positive input of the differential amplifier, the output of the second differential amplifier is connected to the negative input of the differential amplifier and wherein the output of the differential amplifier is connected by the at least one address switch to the data buss.

11. A photosurface according to claim 6 or claim 7 wherein the at least one capacitor is connected to the at least one amplifier by a plurality of switches such that:

for a first combination of open and closed switches a first terminal of the at least one capacitor is connected to the input of the amplifier and a second terminal of the at least one capacitor is connected to the output of the amplifier; and

for a second combination of open and closed switches the first terminal of the at least one capacitor is connected to the output of the amplifier and the second terminal of the at least one capacitor is connected to the input of the amplifier.

12. A photosurface according to any of claims 1-5 wherein the at least one variable connection comprises at least one modulator.

13. A photosurface according to claim 12 wherein the at least one modulator comprises one modulator and wherein the at least one capacitor comprises one capacitor.

14. A photosurface according to claim 12 or claim 13 wherein the at least one modulator is controllable to modulate the current from the light sensitive element harmonically.

15. A photosurface according to claim 13 wherein the at least one modulator is controllable to modulate the current from the light sensitive element pseudo randomly.

16. A 3D camera for determining distances to objects in a scene comprising a photosurface according to claim 5 or claim 6.

17. A 3D camera according to claim 16 comprising a controller that gates each pixel in the photo surface on and off by controlling the gate switch associated with the capacitor to be closed or open.

18. A 3D camera according to claim 17 comprising a light source that radiates a plurality of light pulses, having a pulse width, that illuminate objects in the scene, wherein the controller gates pixels in the photosurface on or off at times coordinated with times at which light pulses of the plurality of light pulses are radiated.

19. A 3D camera for determining distances to objects in a scene comprising a photosurface according to any of claim 8-10.

20. A 3D camera according to claim 19 comprising a controller that gates pixels in the photo surface on and off by controlling at least one of the first and second gate switches of the circuits of the pixels to be closed or open.

21. A 3D camera according to claim 20 comprising a light source that radiates a plurality of light pulses that illuminate objects in the scene, the light pulses having a pulse width, wherein the controller gates pixels in the photosurface on or off at times responsive to times at which light pulses of the plurality of light pulses are radiated.

22. A 3D camera according to claim 21 wherein the controller is operative to:

gate pixels on for a first gate period after a first time lapse following each radiated light pulse of a first plurality of radiated light pulses such that current from the light sensitive element is integrated by the first integrator; and

gate pixels on for a second gate period after a second time lapse following each radiated light pulse of a second plurality of radiated light pulses such that current from the light sensitive element is integrated by the second integrator.

23. A 3D camera according to claim 22 wherein the mid points of first and second gate periods are delayed with respect to the radiated light pulses that they respectively follow by the same amount of time.

24. A 3D camera according to claim 22 or claim 23 wherein the duration of the first gate period is substantially equal to the pulse width of the radiated light pulses.

25. A 3D camera according to any of claims 22 - 24 wherein the duration of the second gate is greater than or equal to three times the pulse width.

26. A 3D camera according to claim 21 wherein the controller is operative to:

gate pixels on for a first gate period after a first time lapse following each radiated light pulse of the plurality of radiated light pulses such that current from the light sensitive element is integrated by the first integrator; and

gate pixels on for a second gate period after a second time lapse following each radiated light pulse of the plurality of the plurality of radiated light pulses such that current from the light sensitive element is integrated by the second integrator.

27. A 3D camera according to claim 26 wherein the first time lapse is such that light reflected from the object reaches the light sensitive element during the first gate period, such that current therefrom responsive to background light, light reflected from the radiated light pulse by objects in the scene plus dark current is integrated on the first integrator.

28. A 3D camera according to claim 26 or claim 27 wherein the second time lapse is such that light reflected from the object does not reach the light sensitive element during the second gate period, such that current therefrom responsive to background light plus dark current is integrated on the second integrator.

29. A 3D camera for determining distances to objects in a scene comprising a photosurface according to claim 11.

30. A 3D camera according to claim 29 comprising a controller that gates pixels in the photo surface on and off by controlling the at least one gate switch in the circuits of the pixels to be closed or open.

31. A 3D camera according to claim 30 comprising a light source that radiates a plurality of light pulses having a pulse width that illuminate objects in the scene and wherein the controller gates pixels in the photosurface on or off at times responsive to times at which light pulses of the plurality of light pulses are radiated.

32. A 3D camera according to claim 31 wherein the controller gates pixels on for a first and second gate periods following each light pulse in the plurality of light pulses and wherein during the first gate period current in the light sensitive element is responsive to background light and light of the radiated light pulse reflected from the objects in the scene plus dark current is integrated on the capacitor and increases voltage across the capacitor and wherein during the second gate current responsive to background light plus dark current is integrated on the capacitor and decreases voltage across the capacitor.

33. A 3D camera according to any of claims 26-28 or claim 32 wherein the duration of the first gate and the duration of the second gate are controlled to be equal to a high degree of accuracy.

34. A 3D camera according to any of claims 26-28, 32 or 33 wherein the duration of the first and second gates is substantially equal to the pulse width of the radiated light pulses.

35. A 3D camera according to any of claims 17-34 wherein the pixel circuit of the photosurface comprises a reset switch connected to the light sensitive element and wherein when the reset switch is closed, voltage across the light sensitive element is set to a predetermined magnitude.

36. A 3D camera according to claim 35 wherein the controller controls the reset switch and wherein before the controller gates a pixel on the controller closes and opens the reset switch of the pixel at least once.

37. A 3D camera for determining distances to objects in a scene comprising a photosurface according to claim 12.

38. A 3D camera according to claim 37 comprising a controller that controls modulators in the pixels of the photosurface to modulate currents from the light sensitive elements of the pixels.

39. A 3D camera according to claim 38 wherein the modulators modulate the currents harmonically.

40. A 3D camera according to claim 39 wherein different pixels of the photosurface are modulated at different frequencies of modulation.

41. A 3D camera according to claim 38 comprising a light source that radiates a beam of light having an harmonically modulated intensity and wherein the controller controls the modulators to modulate the currents harmonically so that the beam of light and the currents are modulated harmonically at the same frequency of modulation and in phase.

42. A 3D camera according to any of claims 17, 18, 20-28, 30-36 or 38-41 wherein the controller controls each pixel of the pixels in the photosurface independently of other pixels in the photosurface.

43. A 3D camera according to any of claims 17, 18, 20-28, 30-36 or 38-41 wherein pixels in the photosurface are grouped into different pixel groups and pixels in a same pixel group are controlled by the controller simultaneously and wherein each pixel group is controlled independently of other pixel groups.

44. A method of removing the effects of background and dark current from a signal generated from a gated reflection of a pulsed source of light reflected from an object, the method comprising;

generating a value based on gating a reflection of a pulsed source of light reflected from an object;

generating a second value based on gating when no reflected light is present; and

subtracting the values to form a corrected values.

45. A method according to claim 44 wherein the gating of the reflection of the pulsed source is so timed and of such a duration that only a portion of the light from the source reflected from the object is utilized in generating the value.

46. A method according to claim 44 wherein the gating of the reflection of the pulsed source is so timed and of such a duration that all of the light from the source reflected from the object is utilized in generating the value, such that the value is a normalizing value.

47. A method of removing the effects of background and dark current from a signal generated from a gated reflection of a pulsed source of light reflected from an object and normalizing the signal, the method comprising;

providing a value generated in accordance with claim 45;

providing a normalizing value generated in accordance with claim 46; and

normalizing the value generated in accordance with claim 45 utilizing the normalizing value.

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WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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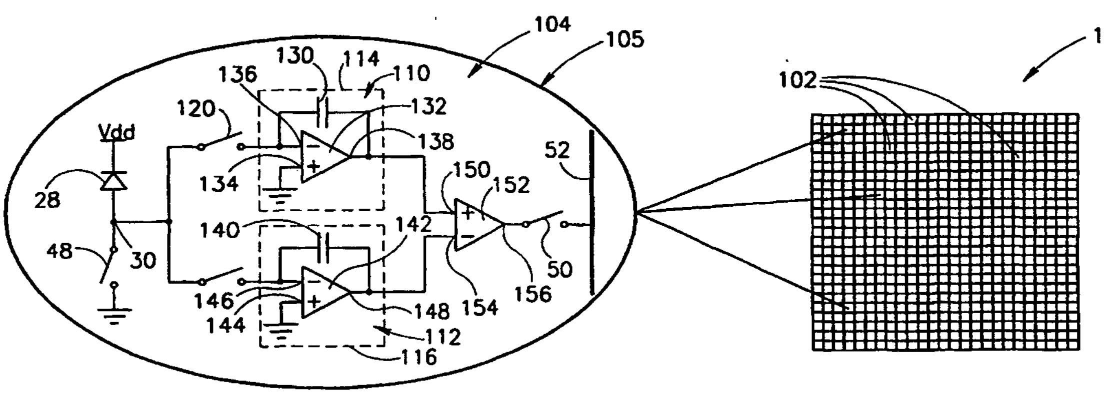

(57) Abstract

A photosurface comprising a plurality of light sensitive pixels, wherein each pixel of the plurality of pixels comprises an electronic circuit, each of the circuits comprising: a single light sensitive element that provides a current responsive to light incident thereon; at least one charge accumulator separate from the light sensitive element; and at least one variable connection through which current flows from the light sensitive element into the integrator.

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DISTANCE MEASUREMENT WITH A CAMERA

FIELD OF THE INVENTION

The invention relates to cameras that provide measurements of distances to objects and parts of objects that they image and in particular to integrating functions of such cameras on a single chip.

BACKGROUND OF THE INVENTION

Three dimensional optical imaging systems, hereinafter referred to as "3D cameras", that are capable of providing distance measurements to objects and points on objects that they image, are used for many different applications. Among these applications are profile inspection of manufactured goods, CAD verification, robot vision, geographic surveying and imaging objects selectively as a function of distance.

Some 3D cameras provide simultaneous measurements to substantially all points of objects in a scene they image. Generally, these 3D cameras comprise a light source, such as a laser, which is pulsed or shuttered so that it provides pulses of light for illuminating a scene being imaged and a gated imaging system for imaging light from the light pulses that is reflected from objects in the scene. The gated imaging system comprises a camera having a photosensitive surface, hereinafter referred to as a "photosurface", such as a CCD camera, and a gating means for gating the camera open and closed, such as an optical shutter or a gated image intensifier. The reflected light is registered on pixels of the photosurface of the camera only if it reaches the camera when the camera is gated open.

To image a scene and determine distances from the camera to objects in the scene, the scene is generally illuminated with a train of light pulses radiated from the light source. For each radiated light pulse in the train, following an accurately determined delay from the time that the light pulse is radiated, the camera is gated open for a period of time hereinafter referred to as a "gate". Light from the light pulse that is reflected from an object in the scene is imaged on the photosurface of the camera if it reaches the camera during the gate. Since the time elapsed between radiating a light pulse and the gate that follows it is known, the time it took imaged light to travel from the light source to the reflecting object in the scene and back to the camera is known. The time elapsed is used to determine the distance to the object.

In some of these 3D cameras, only the timing between light pulses and gates is used to determine the distance from the 3D camera to a point in the scene imaged on a pixel of the photosurface of the 3D camera. In others, the *amount* of light registered by the pixel during the time that the camera is gated open is also used to determine the distance. The accuracy of

measurements made with these 3D cameras is a function of the rise and fall times and jitter of the light pulses and their flatness, how fast the gating means can gate the camera open and closed.

A 3D camera using a pulsed source of illumination and a gated imaging system is described in "Design and Development of a Multi-detecting two Dimensional Ranging Sensor", Measurement Science and Technology **6** (September 1995), pages 1301-1308, by S. Christie, et al., and in "Range-gated Imaging for Near Field Target Identification", Yates et al, SPIE Vol. 2869, p374 - 385 which are herein incorporated by reference.

Another 3D camera is described in U.S. patent 5,081,530 to Medina, which is incorporated herein by reference. A 3D camera described in this patent registers energy in a pulse of light reflected from a target that reaches the camera's imaging system during each gate of a pair of gates. Distance to a target is determined from the ratio of the difference between the amounts of energy registered during each of the two gates to the sum of the amounts of energy registered during each of the two gates.

A variation of a gated 3D camera is described in U.S. patent 4,935,616 to Scott, which is incorporated herein by reference. In this patent, a 3D camera is described in which a light source and imaging system, instead of being fully gated, are "modulated". In a preferred embodiment of the invention, the light source comprises a CW laser. The intensity of light radiated by the laser is modulated so that the intensity has an harmonically varying component. The sensitivity of the camera's imaging system to light is also harmonically modulated. When a target that is illuminated by the modulated laser light reflects some of the incident laser light, the reflected light has the same modulation as the laser light. However, modulation of the reflected light that reaches the imaging system from the target has a phase difference with respect to the modulation of the imaging system that depends upon the distance of the target from the camera. The intensity that the camera registers for the reflected light is a function of this phase difference. The registered intensity is used to determine the phase difference and thereby the distance of the target from the camera.

Other "gated" 3D cameras and examples of their uses are found in PCT Publications WO97/01111, WO97/01112, and WO97/01113 which are incorporated herein by reference.

An optical shutter suitable for use in 3D cameras is described in PCT patent application PCT/IL98/00060, by some of the same applicants as the applicants of the present application, the disclosure of which is incorporated herein by reference.

SUMMARY OF THE INVENTION

Some aspects of preferred embodiments of the present invention relate to providing an improved 3D camera wherein gating or modulating apparatus for the 3D camera is incorporated on a photosurface of the camera on which light detectors of the camera are also situated.

In accordance with one aspect of some preferred embodiments of the present invention, each pixel in the photosurface includes its own pixel circuit for gating the pixel on or off or for modulating the sensitivity of the pixel to incident light.

In some preferred embodiments of the present invention the same pixel circuit functions to gate the pixel on or off and to modulate the sensitivity of the pixel to incident light.

In some preferred embodiments of the present invention each pixel is gated on or off or modulated independently of other pixels. In other preferred embodiments of the present invention pixels on the photosurface are grouped into different pixel groups. The pixels belonging to a same pixel group are gated on or off or modulated substantially simultaneously. Pixel groups are gated on and off or modulated in different combinations and time sequences.

In some preferred embodiments of the present invention, pixels in different pixel groups are located in different regions of the photosurface. In some preferred embodiments of the present invention, the different regions are different parallel bands of pixels of the photosurface. In some preferred embodiments of the present invention, the different regions are substantially equal area regions of the photosurface.

Some aspects of preferred embodiments of the present invention relate to providing a photosurface that images a scene and provides measurements of distances to objects in the scene in a single frame.

Some aspects of preferred embodiments of the present invention relate to providing a photosurface that comprises pixels having outputs that are automatically corrected for biases and noise resulting from background light and dark current from a light sensitive element of the pixel.

In accordance with another aspect of some preferred embodiments of the present invention, a photosurface is provided comprising pixels, wherein each pixel includes a photodiode or other, preferably linear, light sensitive current source such as a photoresistor, or photogate, a charge accumulator, hereinafter referred to as, but not necessarily limited to an "integrator" and a variable connection. The photodiode is connected to the integration circuit via the variable connection. Preferably, the integrator comprises an amplifier, preferably, an operational amplifier with capacitive feedback.

In some preferred embodiments of the present invention the variable connection is a switch controllable to be either open or closed. When the photodiode is exposed to light to which it is sensitive and the pixel control switch is closed, a current flows into the integrator from the photodiode that is substantially proportional to the intensity of light incident on the photodiode. A charge, hereinafter referred to as a "photocharge", is accumulated by an integrator. The amount of photocharge accumulated is proportional to the integral over time of the intensity of light to which the photodiode is exposed during the time that the pixel control switch is closed. The integrated photocharge is used as a measure of the pixel response to the light to which it is exposed. The switch is said to gate the pixel on when the switch is closed and to gate the pixel off when the switch is open. The switch is hereinafter referred to as a "gate switch".

In some preferred embodiments of the present invention the variable connection operates to modulate the sensitivity of the pixel to incident light. In these preferred embodiments, the modulator is controllable, using methods known in the art, so that the magnitude of the resistance between the photodiode and the integrator across the modulator can be set to values within some range of values. When light is incident on the photodiode, the magnitude of photocurrent flowing between the photodiode and the storage capacitor is a function not only of the intensity of the incident light but also of the value of the modulator resistance. By controlling the value of the modulator resistance the amount of photocharge integrated by the integrator in a given period of time for a given intensity of incident light, and thereby the sensitivity of the pixel to incident light, is controlled or modulated. When operating in a modulating mode the variable connection is referred to as a "modulator".

In some preferred embodiments of the present invention the modulator modulates pixels so that pixel sensitivities vary harmonically. In some preferred embodiments of the present invention all pixels in a photosurface are modulated harmonically with a same frequency of modulation. In other preferred embodiments of the present invention different groups of pixels in a photosurface are modulated harmonically with different frequencies.

In some preferred embodiments of the present invention a variable connection is controllable to function only as a gate switch. In other preferred embodiments of the present invention it is controllable to function only as a modulator. In still other preferred embodiments of the present invention, it may be controllable to function as either a gate switch or a modulator. The pixel control switch is appropriately connected using methods known in the art,

via a control line, to a controller that transmits control signals to operate the pixel control switch as a gating switch or as a modulator.

Gate switches and modulators of pixels in a photosurface can be controlled, in accordance with preferred embodiments of the present invention, to gate or modulate different combinations of pixels and to gate pixels and groups of pixels with different timing sequences. Similarly, pixel storage capacitors can be addressed and "read" in different combinations and in different timing sequences.

Preferably, the pixels are packed on the photosensitive surface with a pitch less than 50 microns. More preferably the pixels are packed with a pitch less than 30 microns. Preferably, the photosurface is produced using CMOS technology and the pixel control switch is a FET or MOSFET. Using CMOS technology, light sensitive photosurfaces comprising arrays of pixels suitable for visual imaging can be produced, wherein each pixel of the photosurface contains a light sensitive component such as a photo-diode and electronic switching, control and logic elements. For example, US patent 5,345,266 describes a pixel comprising a photodiode and a transistor. Peter Denyer in a talk given at the 1996 SSCTC Workshop On CMOS Imaging Technology, Feb 7, 1996, described a pixel comprising electronic elements that is on the order of 12 microns on a side and in which the photodiode occupies 60 % the pixel area.

There is thus provided, in accordance with a preferred embodiment of the invention, a photosurface comprising a plurality of light sensitive pixels, wherein each pixel of the plurality of pixels comprises an electronic circuit, each of the circuits comprising:

a single light sensitive element that provides a current responsive to light incident thereon;

at least one charge accumulator separate from the light sensitive element; and

at least one variable connection through which current flows from the light sensitive element into the integrator.

Preferably, the charge is accumulated on a capacitor.

Preferably, the at least one charge accumulator comprises at least one amplifier, having an input and an output, the at least one capacitor being connected as a feedback capacitor of the amplifier, and wherein the at least one variable connection connects the light sensitive element to the input of the amplifier. Preferably, the amplifier is an operational amplifier.

Preferably the photosurface comprises at least one data buss and wherein the circuit comprises at least one address switch, which connects a data buss to an output of one of the at least one amplifiers, either directly or via another switch.

Preferably, the at least one variable connection comprises at least one gate switch. Preferably, the at least one capacitor comprises a single capacitor and the at least one gate switch comprises a single gate switch.

In preferred embodiments of the invention, such photosurfaces are used in 3D cameras. Preferably such cameras comprise a controller that gates each pixel in the photo surface on and off by controlling the gate switch associated with the capacitor to be closed or open. Preferably, the camera comprises a light source that radiates a plurality of light pulses, having a pulse width, that illuminate objects in the scene, wherein the controller gates pixels in the photosurface on or off at times coordinated with times at which light pulses of the plurality of light pulses are radiated.

In a preferred embodiment of the invention, the at least one capacitor comprises first and second capacitors connected as feedback capacitors respectively to first and second amplifiers to form first and second integrators; and the at least one gate switch comprises first and second gate switches, the first gate switch connecting the light sensitive element to the input of the first amplifier and the second gate switch connecting the light sensitive element to the input of the second amplifier. Preferably, the at least one address switch comprises first and second address switches, the first address switch connecting the output of the first amplifier to the data buss and the second address switch connecting the output of the second differential amplifier to the data buss.

Alternatively, the photosurface comprises a differential amplifier having positive and negative inputs and an output, wherein the output of the first differential amplifier is connected to the positive input of the differential amplifier, the output of the second differential amplifier is connected to the negative input of the differential amplifier and wherein the output of the differential amplifier is connected by the at least one address switch to the data buss.

In preferred embodiments of the invention, these photosurfaces are used in 3D cameras.

Preferably, the 3D camera comprises a controller that gates pixels in the photo surface on and off by controlling at least one of the first and second gate switches of the circuits of the pixels to be closed or open. Preferably, the 3D camera comprises a light source that radiates a plurality of light pulses that illuminate objects in the scene, the light pulses having a pulse width, wherein the controller gates pixels in the photosurface on or off at times responsive to times at which light pulses of the plurality of light pulses are radiated.

In a preferred embodiment of the invention, the controller is operative to:

gate pixels on for a first gate period after a first time lapse following each radiated light pulse of a first plurality of radiated light pulses such that current from the light sensitive element is integrated by the first integrator; and

gate pixels on for a second gate period after a second time lapse following each radiated light pulse of a second plurality of radiated light pulses such that current from the light sensitive element is integrated by the second integrator.

Preferably, the mid points of first and second gate periods are delayed with respect to the radiated light pulses that they respectively follow by the same amount of time. Preferably, the duration of the first gate period is substantially equal to the pulse width of the radiated light pulses. Preferably, the duration of the second gate is greater than or equal to three times the pulse width.

Alternatively, in a preferred embodiment of the invention the controller is operative to:

gate pixels on for a first gate period after a first time lapse following each radiated light pulse of the plurality of radiated light pulses such that current from the light sensitive element is integrated by the first integrator; and

gate pixels on for a second gate period after a second time lapse following each radiated light pulse of the plurality of the plurality of radiated light pulses such that current from the light sensitive element is integrated by the second integrator.

Preferably, the first time lapse is such that light reflected from the object reaches the light sensitive element during the first gate period, such that current therefrom responsive to background light, light reflected from the radiated light pulse by objects in the scene plus dark current is integrated on the first integrator.

Preferably, the second time lapse is such that light reflected from the object does not reach the light sensitive element during the second gate period, such that current therefrom responsive to background light plus dark current is integrated on the second integrator.

In a preferred embodiment of the invention, the at least one capacitor is connected to the at least one amplifier by a plurality of switches such that:

for a first combination of open and closed switches a first terminal of the at least one capacitor is connected to the input of the amplifier and a second terminal of the at least one capacitor is connected to the output of the amplifier; and

for a second combination of open and closed switches the first terminal of the at least one capacitor is connected to the output of the amplifier and the second terminal of the at least one capacitor is connected to the input of the amplifier.

In preferred embodiments of the invention, the above photosurfaces are used in 3D cameras.

In a preferred embodiment of the invention, the 3D camera comprises a controller that gates pixels in the photo surface on and off by controlling the at least one gate switch in the circuits of the pixels to be closed or open. Preferably, the 3D camera comprises a light source that radiates a plurality of light pulses having a pulse width that illuminate objects in the scene and wherein the controller gates pixels in the photosurface on or off at times responsive to times at which light pulses of the plurality of light pulses are radiated.

Preferably, the controller gates pixels on for a first and second gate periods following each light pulse in the plurality of light pulses and wherein during the first gate period current in the light sensitive element is responsive to background light and light of the radiated light pulse reflected from the objects in the scene plus dark current is integrated on the capacitor and increases voltage across the capacitor and wherein during the second gate current responsive to background light plus dark current is integrated on the capacitor and decreases voltage across the capacitor.

Preferably, the duration of the first gate and the duration of the second gate are controlled to be equal to a high degree of accuracy.

Preferably, the duration of the first and second gates is substantially equal to the pulse width of the radiated light pulses.

Preferably, the pixel circuit of the photosurface comprises a reset switch connected to the light sensitive element and wherein when the reset switch is closed, voltage across the light sensitive element is set to a predetermined magnitude. Preferably, the controller controls the reset switch and wherein before the controller gates a pixel on the controller closes and opens the reset switch of the pixel at least once.

In a preferred embodiment of the invention, the at least one variable connection comprises at least one modulator. Preferably, the at least one modulator comprises one modulator and wherein the at least one capacitor comprises one capacitor. Preferably, the at least one modulator is controllable to modulate the current from the light sensitive element harmonically. Alternatively, the at least one modulator is controllable to modulate the current from the light sensitive element pseudo randomly.

In preferred embodiments of the invention, these photosurface are used in a 3D camera.

preferably, the 3D camera comprises a controller that controls modulators in the pixels of the photosurface to modulate currents from the light sensitive elements of the pixels.

preferably, the modulators modulate the currents harmonically. In one preferred embodiment of the invention, different pixels of the photosurface are modulated at different frequencies of modulation.

In a preferred embodiment of the invention, the 3D camera comprises a light source that radiates a beam of light having an harmonically modulated intensity and wherein the controller controls the modulators to modulate the currents harmonically so that the beam of light and the currents are modulated harmonically at the same frequency of modulation and in phase.

In a preferred embodiment of the invention, the controller controls each pixel of the pixels in the photosurface independently of other pixels in the photosurface. In an alternative preferred embodiment of the invention, pixels in the photosurface are grouped into different pixel groups and pixels in a same pixel group are controlled by the controller simultaneously and wherein each pixel group is controlled independently of other pixel groups.

There is further provided, in accordance with a preferred embodiment of the invention, a method of removing the effects of background and dark current from a signal generated from a gated reflection of a pulsed source of light reflected from an object, the method comprising;

generating a value based on gating a reflection of a pulsed source of light reflected from an object;

generating a second value based on gating when no reflected light is present; and

subtracting the values to form a corrected values.

Preferably, gating of the reflection of the pulsed source is so timed and of such a duration that only a portion of the light from the source reflected from the object is utilized in generating the value.

Alternatively or additionally, gating of the reflection of the pulsed source is so timed and of such a duration that all of the light from the source reflected from the object is utilized in generating the value, such that the value is a normalizing value.

There is further provided, in accordance with a preferred embodiment of the invention, a method of removing the effects of background and dark current from a signal generated from a gated reflection of a pulsed source of light reflected from an object and normalizing the signal, the method comprising;

providing a value in accordance with preferred method described above;

providing a normalizing value generated in accordance with the above method; and

normalizing the value utilizing the normalizing value.

The invention will be more clearly understood by reference to the following description of preferred embodiments thereof read in conjunction with the figures attached hereto. In the figures identical structures, elements or parts which appear in more than one figure are labeled with the same numeral in all the figures in which they appear. The figures are listed below and:

BRIEF DESCRIPTION OF FIGURES

Fig. 1A shows a schematic of a photosurface and a circuit diagram of pixels in the photosurface, in accordance with a preferred embodiment of the present invention;

Fig. 1B shows a schematic of a photosurface divided into band shaped pixel groups, in accordance with a preferred embodiment of the present invention;

Fig. 1C shows a schematic of a photosurface divided into square shaped pixel groups, in accordance with a preferred embodiment of the present invention;

Fig. 1D shows a schematic of a photosurface divided into pixel groups that are used to simultaneously provide an image of a scene and distance measurements to points in the scene, in accordance with a preferred embodiment of the present invention;

Fig. 2 shows a schematic of a photosurface and a circuit diagram of pixels in the photosurface, in accordance with another preferred embodiment of the present invention, in which the pixel circuit comprises a modulator;

Fig. 3 shows a schematic of a photosurface and a circuit diagram of pixels in the photosurface, in accordance with a preferred embodiment of the present invention, in which pixel outputs are automatically corrected for biases due to background light and dark current;

Fig. 4 shows a schematic of another photosurface and a circuit diagram of pixels in the photosurface, in accordance with a preferred embodiment of the present invention, in which pixel outputs are automatically correctable for biases due to background light and dark current;

Fig. 5 shows a time drawing of light and gating pulses illustrating a method of removing background and dark current effects for producing normalized light values; and

Fig. 6 shows a schematic of a photosurface being used to determine distances to objects in a scene, in accordance with a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 1A shows a schematic of a photosurface 20 for use in a 3D camera in accordance with a preferred embodiment of the present invention. Elements in Fig. 1A, and in similar subsequent figures, are not shown to scale and their relative sizes have been determined for ease and clarity of presentation. Only those parts of photosurface 20 that are relevant to the discussion are shown in Fig. 1.

Photosurface 20 comprises a plurality of pixels 22, wherein each pixel comprises a pixel circuit 24, in accordance with a preferred embodiment of the present invention, shown schematically and in greatly exaggerated scale in inset 26. Pixel circuit 24 comprises a back biased photodiode 28, connected at a node 30 to a variable connection that operates as a gate switch 36. Gate switch 36 connects photodiode 28 to an integrator 32 shown inside a dotted rectangle 34. Integrator 32 comprises a storage capacitor 38 and an amplifier 40 having a positive input 42, a negative input 44 and an output 46. Voltage on output 46 is substantially proportional to charge on capacitor 38. Gate switch 36 connects photodiode 28 to negative input 44 when gate switch 36 is closed and disconnects photodiode 28 from negative input 44 when gate switch 32 is open. Positive input 42 is preferably grounded.

A reset switch 48 selectively connects node 30 to ground. When reset switch 48 is closed any intrinsic capacitance of photodiode 28 is charged to Vdd. When both reset switch 48 and gate switch 36 are closed, any accumulated charge on storage capacitor 38 is discharged and voltage on output 46 is set to zero.

Output 46 of amplifier 40 is connected via an address switch 50 to a readout bus 52. Address switch 50, reset switch 48 and gate switch 36 are controlled to be closed and open by control signals from a controller to which they are connected by control lines (not shown) using methods known in the art. Preferably, the controller and photosensitive surface 20 are integrated on a same substrate (not shown).

In a typical operating cycle of a pixel 22, in accordance with a preferred embodiment of the present invention, when photosurface 20 is used to determine distances to objects in a scene, the pixel is first reset. This is accomplished by closing reset switch 48 and gate switch 36 to discharge storage capacitor 38. Gate switch 36 is then opened. The scene is then illuminated with a train of light pulses, preferably radiated from a pulsed or shuttered laser. Light reflected from each of the radiated light pulses by objects in the scene is collected by collecting optics (not shown) and focused onto photosurface 20. Preferably, an appropriate filter (not shown) that transmits substantially only light having a wavelength radiated by the laser, shields pixels 22 in photosurface 20.

At accurately determined times following the time that each light pulse is radiated, reset switch 48 is opened and gate switch 36 is closed. Gate switch 36 remains closed for an accurately determined period of time and is then opened. Pixel 22 is thereby sensitive to light from the laser during a gate that has an accurately determined gate width (the period of time

during which gate switch 36 is closed) and an accurately determined start time following the time that each light pulse is radiated.

If photodiode 28 is exposed to light from a radiated light pulse that is reflected from a region of an object in the scene, and/or background light during the gate, a current, hereinafter referred to as a "photocurrent", flows from photodiode 28 into storage capacitor 38. Storage capacitor 38 integrates the photocurrent and a "photocharge" is accumulated on storage capacitor 38. The photocurrent is proportional to the intensity of the light incident on photodiode 28 from the region of the object and from background light. The amount of photocharge accumulated on storage capacitor 38 is equal to the time integral of the photocurrent during the gate.

By opening and closing reset switch 48 each time before closing gate switch 36 it is assured that every time photodiode 28 is connected to input 44 node 30 has been set to ground and the voltage across the intrinsic capacitance of photodiode 28 is set to Vdd. As a result any change in voltage across the intrinsic capacitance of photodiode 28 that occurs during periods of time between gates does not affect the amount of charge integrated by storage capacitor 38 during a gate. Such changes might result from dark currents or light incident on photodiode during periods between gates.

The total amount of photocharge accumulated by storage capacitor 38 for the train of radiated light pulses is the sum of the photocharges accumulated during all of the gates that follow radiated light pulses in the train of light pulses.

Following the last gate, the amount of photocharge on storage capacitor 38 is determined by closing address switch 50. When this occurs output 46 of amplifier 40 is connected to readout buss 52 and a charge is deposited on readout buss 52 that is proportional to the photocharge accumulated on storage capacitor 38. The charge deposited on readout buss 52 is sensed and registered using methods known in the art.

The registered photocharge from pixel 22 is preferably normalized to the reflectivity of the region of the object imaged on pixel 22 using methods described in PCT Publications WO97/01111, WO97/01112, and WO97/01113 referenced above. Corrected and normalized registered photocharges from a plurality of pixels 22 are then processed to provide distances to objects in the scene and images of the objects as described in the referenced PCT publications.

Following the readout of the photocharge, reset switch 48 and gate switch 36 are closed so as to discharge any accumulated photocharge on storage capacitor 38 and reset the voltage on output 46 to zero. A next operating cycle can now be initiated.

Gate switches 36 and reset switches 48 of pixels 22 on photosurface 20 can be controlled, in accordance with preferred embodiments of the present invention, to gate pixels 22 on and off in different combinations and with different timing sequences. In some preferred embodiments of the present invention gate switch 36 and reset switch 48 of each pixel 22 is controlled independently of gate and reset switches 36 and 48 of other pixels 22. Different combinations of pixels 22 are gated on and off in different timing sequences by controlling individual pixels 22. In other preferred embodiments of the present invention pixels 22 are grouped into different "pixel groups". Gate switch control lines to pixels 22 in a same pixel group are appropriately connected together so that pixels 22 belonging to the pixel group are gated on and off together and different combinations of pixel groups are gated on and off in different timing sequences.

In some preferred embodiments of the present invention different pixel groups define different regions of photosurface 20. For example, Fig. 1B shows pixel groups that divide photosurface 20 into parallel strips 60. All pixels 22 in a strip 60 belong to the same pixel group and are gated simultaneously. Fig. 1C shows pixel groups that divide photosurface 20 into square substantially equal area regions 62. Applications of different configurations of pixel groups are described in PCT publication WO 97/01111, referenced above.

A photosurface, in accordance with a preferred embodiment of the present invention, may also be divided into pixel groups that are usable to simultaneously provide images of objects in a scene and distance measurements to the objects.

Assume that the scene is illuminated with a train of light pulses and that light reflected from each of the radiated light pulses by objects in the scene is collected by collecting optics and focused onto the photosurface. The photosurface is divided into pixel groups, in accordance with a preferred embodiment of the present invention, in which each pixel group comprises two contiguous pixel sub-groups, a first pixel subgroup and a second pixel sub-group. Each pixel subgroup includes at least one pixel. Preferably, the area of the second pixel subgroup surrounds the area of the first pixel subgroup. Preferably, the pixel groups of the photosurface have small areas.

The first pixel subgroups of the photosurface are used to perform distance measurements to the objects in the scene. The second pixel subgroups of the photosurface are used to provide images of the objects.

In accordance with a preferred embodiment of the present invention the first pixel subgroup of each pixel group is gated on with a relatively short gate at a predetermined time

following each light pulse in the train of light pulses (i.e. the pixels of the sub-group are simultaneously gated with a relatively short gate). Preferably, the gate width of the short gate is equal to the pulse width of the light pulses in the train of light pulses. The amount of light registered by a pixel in a first pixel subgroup is a function of the distance from the pixel of a region of an object in the scene that is imaged on the pixel and the intensity of light incident on the pixel from the region. The distance to the region is determined from the amount of light registered on the pixel normalized to the intensity of light incident on the pixel from the region.

The second pixel subgroup of each pixel group is gated on with a relatively long gate at a predetermined time following each light pulse in the train of light pulses. Preferably, the gate width of the long gates is at least three times the pulse width of the light pulses. (In the case where the pulse width and the short gate width are not equal, preferably, the long gate width is equal to at least two pulse widths plus a short gate width). Preferably, the mid points of the long and short gates are substantially coincident. The amount of light collected on a pixel of a second subgroup is a function of the intensity of light incident on the pixel from a region of an object in the scene that is imaged on the pixel.

A region imaged by the first subgroup of a pixel group is contiguous with a region imaged by the second subgroup of the pixel group. The intensity of light registered by pixels in the second subgroup of pixels is used to estimate the intensity of light that is incident on pixels in the first subgroup. Estimates of intensity for pixels in the first pixel subgroup are made from intensities registered on pixels in the second pixel subgroup by appropriate averaging and interpolation techniques known in the art. The estimated intensity of incident light on pixels in the first subgroup is used to normalize the amount of light registered on pixels in the first subgroup in order to determine distances to the objects.

Fig. 1D shows photosurface 20 divided into pixel groups 63 that are usable to simultaneously provide an image of an object illuminated by an appropriate train of light pulses and distance measurements to the object, in accordance with a preferred embodiment of the present invention. Each pixel group 63 preferably comprises nine pixels 22. The nine pixels 22 are preferably grouped into a first pixel subgroup 65 comprising a single pixel 22 and a second pixel subgroup 67 comprising eight pixels 22. Inset 70 of Fig. 1D shows a pixel group 63 in which pixels 22 belonging to second subgroup 67 are textured and the single pixel 22 belonging to first pixel subgroup 65 is shown untextured. First pixel subgroup 65 is used for distance measurements to objects in a scene and second pixel subgroup 67 is used for imaging objects in a scene.

Fig. 2 shows a schematic of a photosurface 80 comprising pixels 82 in accordance with another preferred embodiment of the present invention. Each pixel 82 comprises a pixel circuit 84 shown in inset 86. Pixel circuit 84 is identical to pixel circuit 24 shown in Fig. 1A except that in pixel circuit 84 a modulator 88 replaces gate switch 36 in pixel circuit 24. Modulator 88, unlike gate switch 36, modulates current flowing from photodiode 28 into storage capacitor 38 rather than either just preventing photocurrent from flowing or enabling photocurrent to flow into storage capacitor 38. Modulator 88 is preferably a FET and is shown in Fig. 2 by the graphical symbol for a FET. Modulator 88 is connected by a control line 90 to a controller (not shown) that controls the value of the resistance of modulator 88 between photodiode 28 and input 44 of amplifier 40. The resistance of modulator 88 modulates the magnitude of photocurrent that flows through photodiode 28 into storage capacitor 38.

When pixels 82 in photosurface 80 are modulated harmonically, in accordance with a preferred embodiment of the present invention, photosurface 80 is useable to determine distances to objects using an harmonically modulated light source according to methods described in U.S. patent 4,935,616 cited above.

For example, assume that a target (not shown) located at a distance D from photosurface 80 is illuminated with laser light that is modulated so that the intensity of the laser light may be written as $I = I_0(1+\sin(\omega t))$. Assume that pixels 82 of photosurface 80 are harmonically modulated, in accordance with a preferred embodiment of the present invention, so that the sensitivity of pixels 82 can be represented by $S = So(0.5)(1+\sin(\omega t)$. Assume further that light reflected by the target is properly collected and focused onto photosurface 80 for a period of time equal to NT where N is an integer and $T = 2\pi/\omega$, is the period of modulation of the laser light and the pixel sensitivities. Then the amounts of photocharge accumulated on a capacitors 30 of pixels 82, onto which an image of the target is focused, will be proportional to $RI_0S_0(NT)(0.5 + 0.25\cos\vartheta)$ where R is a proportionality constant and $\vartheta = 2D\omega/c$ where c is the speed of light. The amplitude, $RI_0S_0(NT)$, can be determined, in accordance with a preferred embodiment of the present invention, by imaging the target with modulated laser light for a known period of time, which period of time is preferably equal to NT, without modulating the sensitivity of pixels 82.

In the above example pixels 82 of photosurface 80 are modulated harmonically. In some preferred embodiments of the present invention pixels are modulated non-harmonically. For example, pixels may be modulated pseudo-randomly.

Fig. 3 shows another photosurface 100 comprising pixels 102 for use in a 3D camera in accordance with a preferred embodiment of the present invention, to determine distances to objects in a scene. Like photosurface 20 shown in Fig. 1A, photosurface 100 is preferably used with a pulsed or shuttered laser and is preferably shielded by an appropriate optical filter that transmits substantially only light having a wavelength equal to that of light radiated by the laser.

However, unlike pixels 22 in photosurface 20, the outputs of pixels 102 in photosurface 100 are automatically corrected for biases caused by background light to which they are exposed and from dark currents. Background light is any light incident on pixels 102 that is not from light radiated to illuminate objects in the scene. Such background light may originate from sources of light (natural as well as man made) other than the laser that radiate light having the same wavelengths as light radiated by the laser. Background light might also arise because the optical filter that shields photosurface 100 might not be perfectly opaque to light having wavelengths not radiated by the laser.

Pixels 102 comprise a pixel circuit 104 shown in greatly exaggerated scale in inset 105. Pixel circuit 104 comprises a photodiode 28 connected to a node 30 and preferably back biased with a voltage Vdd, and first and second integrators 110 and 112 respectively shown inside dotted circles 114 and 116. First and second integrators 110 and 112 are preferably identical and similar in structure and operation to integrator 32 shown in Fig. 1A as part of pixel circuit 24. A first gate switch 120 is used to connect and disconnect photodiode 28 to and from first integrator 110 and a second gate switch 122 is used to connect and disconnect photodiode 28 to and from second integrator 112.

First integrator 110 comprises a first storage capacitor 130 and first amplifier 132, which amplifier 132 has positive and negative inputs 134 and 136 and an output 138. Second integrator 112 has a second storage capacitor 140 and an amplifier 142 having positive and negative inputs 144 and 146 and an output 148. Preferably, integrators 110 and 112 are identical. Output 138 of first integrator 132 is connected to a positive input 150 of an amplifier 152 and output 148 of second amplifier 142 is connected to a negative input 154 of amplifier 152. Amplifier 152 has an output 156. Voltage on output 156 is proportional to the difference of voltages on outputs 138 and 148. This voltage is proportional to the charge generated by reflection from the object of light from the illumination source.

When first gate switch 120 is closed and second gate switch 122 is open, photocurrent from photodiode 28 is integrated by first storage capacitor 130. Similarly, when first gate

switch 120 is open and second gate switch 122 is closed, photocurrent from photodiode 28 is integrated by second storage capacitor 140. Node 30 is connected to a reset switch 48. When reset switch 48 is closed the intrinsic capacitance of photodiode 28 is charged to voltage Vdd. When reset switch 48 and gate switch 120 are closed storage capacitor 130 is discharged. Similarly, storage capacitor 140 is discharged when reset switch 48 and gate switch 122 are closed.

Output 156 of differential amplifier 152 is connected via an address switch 50 to a readout buss 52. When address switch 50 is closed, voltage on output 156, which is proportional to the difference between the amounts of photocharge on first and second storage capacitors 130 and 140 respectively, is sensed via on readout buss 52. The sensed voltage is a measure of the intensity of the response of a pixel 102 to light from an object imaged on the pixel 102.

A controller (not shown) controls each of the switches in circuit 100 via appropriate control lines (not shown) that connect the controller to the switches.

When photosurface 100 is used to determine distances to objects in a scene, a train of light pulses radiated from the laser illuminates the scene. Following each light pulse in the train of radiated light pulses, each pixel 102 in photosurface 100 that is used to determine distances to the objects is gated on twice.

The first time a pixel 102 is gated on, for a “first gate”, photodiode 102 is connected to first integrator 110 and disconnected from second integrator 112 and photocurrent is integrated on first storage capacitor 130. The second time pixel 102 is gated on, for a “second gate”, photodiode 102 is connected to second storage capacitor 140 and disconnected from first capacitor 110 so that photocurrent is integrated on second storage capacitor 140. The gate widths of the first and second gates are controlled to be equal to a high degree of accuracy. Each time before photodiode 28 is connected to one or the other of integrators 110 and 112, reset switch 48 is closed so as to charge the intrinsic capacitance of photodiode 28 to Vdd and set the voltage of node 30 to ground. As explained in the discussion of Fig. 1A this prevents any changes in voltage across the intrinsic capacitance of photodiode 28 that occur between gates from affecting the amounts of charge accumulated on storage capacitors 130 and 140.

The first gate is timed with respect to the radiated light pulse so that pixel 28 accumulates photocharge on first storage capacitor 130 generated by light incident on photodiode 28 that is reflected from the radiated light pulse by an object in the scene. During the first gate, storage capacitor 130 also accumulates photocharge from background light and

charge generated by dark current in photodiode 28. The voltage on output 138 of first amplifier 132 is therefore proportional to dark current, photocurrent generated by background light and light reflected by an object in the scene that is integrated during the first gate.

The second gate is timed to follow the first gate after a sufficiently long delay so that light from the radiated light pulse reflected by objects in the scene is no longer incident on pixel 102. During the second gate therefore, pixel 102 accumulates photocharge on second storage capacitor 140 generated only by background light and dark current. The voltage on output 148 of second amplifier 142 is therefore proportional to dark current and photocurrent generated by background light that is integrated during the second gate.

Since the voltage on output 156 of amplifier 152 is proportional to the difference between the voltages on output 138 of first amplifier 132 and output 148 of second amplifier 142, the output of pixel 102 is proportional to photocharge generated only by light that is from the radiated light pulse that is reflected by an object in the scene. Biases in the response of pixel 102 to light resulting from background light and from dark current are substantially removed.

In a variation of pixel circuit 104 amplifier 152 is omitted and each of first and second integrators 110 and 112 respectively is connected to data buss 52 by its own address switch. In this variation of pixel circuit 104, following the last radiated light pulse in the train of light pulses, the voltage on output 138 and 148 of each pixel 102 is separately read out and corrections for the effects of background light and dark current on the output of each pixel 102 is preferably performed digitally.

Fig. 4 schematically shows another photosurface, photosurface 170, comprising pixels 172 wherein each pixel 172 comprises a pixel circuit 174 shown in inset 176 that automatically corrects the output of the pixel for biases causes by background light and dark current in accordance with a preferred embodiment of the present invention. This circuit operates with one capacitor and one amplifier and removes the effects of background light and dark current by switching the direction in which current flows into the capacitor.

Pixel circuit 174 comprises an amplifier 178 and five gate switches, gate switches 180, 181, 182, 183 and 184, which control the operating cycle of pixel circuit 174 and route photocurrent from a photodiode 28 (back biased by voltage Vdd) to a storage capacitor 186. Amplifier 178 has positive and negative inputs 190 and 192 and an output 194. Output 194 can be connected to a readout buss 52 by an address switch 50. Storage capacitor 186 is connected

between two nodes, 196 and 198. A reset switch 48 connected to a node 30 is used to ground node 30 and reset the voltage across the intrinsic capacitance of photodiode 28 to Vdd.

Photosurface 170 is useable to measure distances to a target illuminated by a train of light pulses, in accordance with a preferred embodiment of the present invention. Following each light pulse in the train of light pulses, pixels 172 are gated on twice. Each pixel 172 is gated on for a first gate following the light pulse to receive reflected light from the target and subsequently gated on for a second gate to receive background light and measure dark current. The second gate is delayed with respect to the first gate so that during the second gate no reflected light from the target is incident on pixel 172. The gate widths of the two gates are carefully controlled to be equal to a high degree of accuracy. Preferably the gate widths of the two gates are substantially equal to the pulse widths of the light pulses that illuminate the target.

In a typical operating cycle of a pixel 172, capacitor 30 is reset before the first pulse of a train of light pulses illuminating a target by closing gate switches 181 and 182 or gate switches 183 and 184. Thereafter, following each light pulse, reset switch 48 is closed while gate switch 180 is open in order to reset the voltage across the intrinsic capacitance of photodiode 28 to Vdd. Pixel 172 is then gated on for a first gate following (after an appropriate time delay) the light pulse by opening gate switch 48 and closing gate switches 180, 181 and 183. Node 196 is connected thereby to output 194 of amplifier 178 and node 198 is connected to negative input 192 of amplifier 178. During the first gate, photocurrent generated by light reflected by the target and background light, plus dark current, flow into storage capacitor 186 and increase the potential difference across storage capacitor 186. At the end of the first gate, gate switches 180, 181 and 183 are opened and subsequently reset switch 48 is closed to again reset the voltage across the intrinsic capacitance of photodiode 28 to Vdd.

To begin the second gate, reset switch 48 is opened and gate switches 180, 182 and 184 are closed (gate switches 181 and 183 are open). Nodes 196 and 198, which during the first gate were connected to output 194 and input 192 respectively, now have their connections reversed. Node 196 is connected to input 192 and node 198 is connected to output 194. As a result, current from photodiode 28 that flows into storage capacitor 186 during the second gate reduces the voltage across storage capacitor 186. This current is the sum of dark current and photocurrent generated by background light. Therefore at the end of the second gate the contribution to the potential difference across capacitor 186 that existed at the end of the first gate due to dark current and photocurrent generated by background light is subtracted from the

voltage across storage capacitor 186. At the end of the second gate, the potential difference across capacitor 186 and the charge accumulated on the capacitor is due only to light reflected by the target from the light pulse.

Voltage on output 194 of amplifier 178 is therefore proportional only to the amount of photocharge generated by light from the train of light pulses that is reflected by the target. The effects of background light and dark current have been effectively eliminated from the output of pixels 172 in photosurface 170. To read the output of pixel 172 following the last pulse of the train of light pulses, gate switch 50 is closed to connect output 194 to readout buss 52.

In order to determine distances to the target the output of each pixel 172 used to measure distance to the target must be normalized to the intensity of the reflected light incident on the pixel from the region of the target that is imaged on the pixel. This is preferably done by grouping pixels 172 in photosurface 170 into pixel groups and using some of the pixel groups to acquire distance data from the target and using other pixel groups to acquire imaging data (intensity data) as described in the discussion of Fig. 1D. Alternatively photosurface 170 may be exposed twice to the target, once to acquire a frame of distance data from the target and a second time to acquire a frame of imaging data from the target. As described above both the distance data and the imaging data are automatically corrected for the effects of background light and dark current. Outputs of pixels 172 that are used to acquire image data from the target are used to normalize outputs of pixels 172 that are used to acquire distance data from the target.

Fig. 5 shows a generalized system for producing normalized, background and dark-current corrected signals, in accordance with a preferred embodiment of the invention. Fig. 5 is a time drawing in which the timing of two pulses and four gates are shown. A background and dark current corrected signal is derived by accumulating charge from a light sensitive device during a first gating period 302. This includes charge generated by source light reflected from the object 300 during (part of) the period as well as charge generated by background light and dark current 301. During a second gating period 304, preferably having the same extent as gate 302, charge which is accumulated is caused only by background and leakage current. The difference between the two shaded areas corresponds to the *net* charge from the source light reflected from the object. This difference is, however, not yet normalized.

In order to normalize, the total amount of light from source during the entire period of its illumination by the source is accumulated, as in the prior art, during a third gating period 306, which is made long enough to include all of the reflected light 300. As with respect to

period 302, the light during this period includes background, source reflection and dark current. During a fourth gate 308, preferably having the same width as gate 306, charge is accumulated which has as its source only background and dark current. When this charge is subtracted from the charge accumulated during period 306, a true normalizing value (net of background and dark current) is determined. This "net" normalizing signal is used to normalize the net source light reflection charge, as determined from the accumulations during gates 302 and 304.

Fig. 5 shows gates 302/304 and 306/308 acquired in pairs on successive pulses. For this case, the charges may be accumulated utilizing for example a circuit such as that shown in Fig. 3 or 4. However, as described above, they may be acquired for the same pulse utilizing different, adjacent pixels or during different frames, in which case the circuit of Fig. 1A may be used. However, it should be understood that the methodology described with respect to Fig. 5 has more general applicability than to the photosurfaces described above and can be utilized in a wider range of pulsed detection systems for the elimination of background and dark current and for normalization.

Fig. 6 schematically shows a photosurface 200 having pixels 202 comprised in a 3D camera that is being used to determine distances to an object 204, in accordance with a preferred embodiment of the present invention. Only the parts of the 3D camera that are relevant to the discussion are shown. Elements shown in Fig. 6 are not to scale and their relative dimensions have been chosen to facilitate ease and clarity of exposition.

The 3D camera comprises a light source, preferably a laser 206, that illuminates objects being imaged with a train of light pulses or a light beam having a modulated intensity. A lens 208 collects light from objects imaged by the 3D camera and focuses the collected light on pixels 202 of photosurface 200. 3D camera comprises a controller 210 that synchronizes gating or modulating pixels 202 with light pulses or with the intensity modulation of light radiated by laser 206, respectively.

In the case that laser 206 radiates light pulses, pixels 202 are “gated” pixels that comprise pixel circuits, in accordance with a preferred embodiment of the present invention, of the types shown in Figs. 1A, 3, or 4. Pixels 202 are gated in response to the times at which light pulses are radiated by laser 206, in accordance with a preferred embodiment of the present invention, as described above.

In the case where laser 206 radiates an intensity modulated light beam, pixels 202, are “modulated” pixels that comprise, in accordance with a preferred embodiment of the present invention, pixel circuits of the type shown in Fig. 2. Pixels 202 are modulated in response to

the time dependence of the intensity modulation, in accordance with a preferred embodiment of the present invention, as described above.

In Fig. 6 laser 206 is shown illuminating object 204 with a plurality of light pulses represented by wavy arrows 212. Regions of object 204 reflect light from radiated light pulses 212 in reflected light pulses that are represented by wavy arrows 214. Controller 210 gates pixels 202 on and off with respect to the times that light pulses 212 are radiated, pulse widths of light pulses 212, and a range of distances to object 204 that it is desired to measure.

As discussed explicitly for photosurface 24 shown in Fig. 1A, pixels in the other photosurfaces in accordance with preferred embodiments of the present invention that are described above may be gated (or modulated as the case might be) in different combinations and with different timing sequences. Furthermore, pixels may be controlled individually or in groups.

It should also be recognized that different pixels or pixel groups in photosurfaces, in accordance with preferred embodiments of the present invention, may be made sensitive to different wavelengths of light. For example, in some preferred embodiments of the present invention, pixels in a photosurface are grouped into groups of three contiguous pixels in which each pixel is sensitive to a different one of the primary additive colors R, G, B.

Furthermore, whereas preferred embodiments of the present invention are shown comprising a photodiode as an element that generates current in a pixel circuit in response to incident light, other light sensitive current generators, such as photoresistors or photogates may be used instead of the photodiodes shown.

The present invention has been described using non-limiting detailed descriptions of preferred embodiments thereof that are provided by way of example and are not intended to limit the scope of the invention. Variations of embodiments described will occur to persons of the art. The scope of the invention is limited only by the following claims. In the claims, when the words "comprise", "include" or "have" or their conjugations are used they mean "including but not limited to."

CLAIMS

1. A photosurface comprising a plurality of light sensitive pixels, wherein each pixel of the plurality of pixels comprises an electronic circuit, each of the circuits comprising:

a single light sensitive element that provides a current responsive to light incident thereon;

at least one charge accumulator separate from the light sensitive element; and

at least one variable connection through which current flows from the light sensitive element into the integrator.

2. A photosurface according to claim 1 wherein the charge is accumulated on a capacitor.

3. A photosurface according to claim 1 or claim 2 wherein the at least one charge accumulator comprises at least one amplifier, having an input and an output, the at least one capacitor being connected as a feedback capacitor of the amplifier, and wherein the at least one variable connection connects the light sensitive element to the input of the amplifier.

4. A photosurface according to claim 3 wherein the amplifier is an operational amplifier.

5. A photosurface according to claim 3 or claim 4 comprising at least one data buss and wherein the circuit comprises at least one address switch, which connects a data buss to an output of one of the at least one amplifiers, either directly or via another switch.

6. A photosurface according to any of claims 3-5 wherein the at least one variable connection comprises at least one gate switch.

7. A photosurface according to claim 6 wherein the at least one capacitor comprises a single capacitor and the at least one gate switch comprises a single gate switch.

8. A photosurface according to claim 6 wherein:

the at least one capacitor comprises first and second capacitors connected as feedback capacitors respectively to first and second amplifiers to form first and second integrators; and

the at least one gate switch comprises first and second gate switches, the first gate switch connecting the light sensitive element to the input of the first amplifier and the second gate switch connecting the light sensitive element to the input of the second amplifier.

9. A photosurface according to claim 8 wherein the at least one address switch comprises first and second address switches, the first address switch connecting the output of the first amplifier to the data buss and the second address switch connecting the output of the second differential amplifier to the data buss.

10. A photosurface according to claim 8 comprising a differential amplifier having positive and negative inputs and an output, wherein the output of the first differential amplifier is connected to the positive input of the differential amplifier, the output of the second differential amplifier is connected to the negative input of the differential amplifier and wherein the output of the differential amplifier is connected by the at least one address switch to the data buss.

11. A photosurface according to claim 6 or claim 7 wherein the at least one capacitor is connected to the at least one amplifier by a plurality of switches such that:

for a first combination of open and closed switches a first terminal of the at least one capacitor is connected to the input of the amplifier and a second terminal of the at least one capacitor is connected to the output of the amplifier; and

for a second combination of open and closed switches the first terminal of the at least one capacitor is connected to the output of the amplifier and the second terminal of the at least one capacitor is connected to the input of the amplifier.

12. A photosurface according to any of claims 1-5 wherein the at least one variable connection comprises at least one modulator.

13. A photosurface according to claim 12 wherein the at least one modulator comprises one modulator and wherein the at least one capacitor comprises one capacitor.

14. A photosurface according to claim 12 or claim 13 wherein the at least one modulator is controllable to modulate the current from the light sensitive element harmonically.

15. A photosurface according to claim 13 wherein the at least one modulator is controllable to modulate the current from the light sensitive element pseudo randomly.

16. A 3D camera for determining distances to objects in a scene comprising a photosurface according to claim 5 or claim 6.

17. A 3D camera according to claim 16 comprising a controller that gates each pixel in the photo surface on and off by controlling the gate switch associated with the capacitor to be closed or open.

18. A 3D camera according to claim 17 comprising a light source that radiates a plurality of light pulses, having a pulse width, that illuminate objects in the scene, wherein the controller gates pixels in the photosurface on or off at times coordinated with times at which light pulses of the plurality of light pulses are radiated.

19. A 3D camera for determining distances to objects in a scene comprising a photosurface according to any of claim 8-10.

20. A 3D camera according to claim 19 comprising a controller that gates pixels in the photo surface on and off by controlling at least one of the first and second gate switches of the circuits of the pixels to be closed or open.

21. A 3D camera according to claim 20 comprising a light source that radiates a plurality of light pulses that illuminate objects in the scene, the light pulses having a pulse width, wherein the controller gates pixels in the photosurface on or off at times responsive to times at which light pulses of the plurality of light pulses are radiated.

22. A 3D camera according to claim 21 wherein the controller is operative to:

gate pixels on for a first gate period after a first time lapse following each radiated light pulse of a first plurality of radiated light pulses such that current from the light sensitive element is integrated by the first integrator; and

gate pixels on for a second gate period after a second time lapse following each radiated light pulse of a second plurality of radiated light pulses such that current from the light sensitive element is integrated by the second integrator.

23. A 3D camera according to claim 22 wherein the mid points of first and second gate periods are delayed with respect to the radiated light pulses that they respectively follow by the same amount of time.

24. A 3D camera according to claim 22 or claim 23 wherein the duration of the first gate period is substantially equal to the pulse width of the radiated light pulses.

25. A 3D camera according to any of claims 22 - 24 wherein the duration of the second gate is greater than or equal to three times the pulse width.

26. A 3D camera according to claim 21 wherein the controller is operative to:

gate pixels on for a first gate period after a first time lapse following each radiated light pulse of the plurality of radiated light pulses such that current from the light sensitive element is integrated by the first integrator; and

gate pixels on for a second gate period after a second time lapse following each radiated light pulse of the plurality of the plurality of radiated light pulses such that current from the light sensitive element is integrated by the second integrator.

27. A 3D camera according to claim 26 wherein the first time lapse is such that light reflected from the object reaches the light sensitive element during the first gate period, such that current therefrom responsive to background light, light reflected from the radiated light pulse by objects in the scene plus dark current is integrated on the first integrator.

28. A 3D camera according to claim 26 or claim 27 wherein the second time lapse is such that light reflected from the object does not reach the light sensitive element during the second gate period, such that current therefrom responsive to background light plus dark current is integrated on the second integrator.

29. A 3D camera for determining distances to objects in a scene comprising a photosurface according to claim 11.

30. A 3D camera according to claim 29 comprising a controller that gates pixels in the photo surface on and off by controlling the at least one gate switch in the circuits of the pixels to be closed or open.

31. A 3D camera according to claim 30 comprising a light source that radiates a plurality of light pulses having a pulse width that illuminate objects in the scene and wherein the controller gates pixels in the photosurface on or off at times responsive to times at which light pulses of the plurality of light pulses are radiated.

32. A 3D camera according to claim 31 wherein the controller gates pixels on for a first and second gate periods following each light pulse in the plurality of light pulses and wherein during the first gate period current in the light sensitive element is responsive to background light and light of the radiated light pulse reflected from the objects in the scene plus dark current is integrated on the capacitor and increases voltage across the capacitor and wherein during the second gate current responsive to background light plus dark current is integrated on the capacitor and decreases voltage across the capacitor.

33. A 3D camera according to any of claims 26-28 or claim 32 wherein the duration of the first gate and the duration of the second gate are controlled to be equal to a high degree of accuracy.

34. A 3D camera according to any of claims 26-28, 32 or 33 wherein the duration of the first and second gates is substantially equal to the pulse width of the radiated light pulses.

35. A 3D camera according to any of claims 17-34 wherein the pixel circuit of the photosurface comprises a reset switch connected to the light sensitive element and wherein when the reset switch is closed, voltage across the light sensitive element is set to a predetermined magnitude.

36. A 3D camera according to claim 35 wherein the controller controls the reset switch and wherein before the controller gates a pixel on the controller closes and opens the reset switch of the pixel at least once.

37. A 3D camera for determining distances to objects in a scene comprising a photosurface according to claim 12.

38. A 3D camera according to claim 37 comprising a controller that controls modulators in the pixels of the photosurface to modulate currents from the light sensitive elements of the pixels.

39. A 3D camera according to claim 38 wherein the modulators modulate the currents harmonically.

40. A 3D camera according to claim 39 wherein different pixels of the photosurface are modulated at different frequencies of modulation.

41. A 3D camera according to claim 38 comprising a light source that radiates a beam of light having an harmonically modulated intensity and wherein the controller controls the modulators to modulate the currents harmonically so that the beam of light and the currents are modulated harmonically at the same frequency of modulation and in phase.

42. A 3D camera according to any of claims 17, 18, 20-28, 30-36 or 38-41 wherein the controller controls each pixel of the pixels in the photosurface independently of other pixels in the photosurface.

43. A 3D camera according to any of claims 17, 18, 20-28, 30-36 or 38-41 wherein pixels in the photosurface are grouped into different pixel groups and pixels in a same pixel group are controlled by the controller simultaneously and wherein each pixel group is controlled independently of other pixel groups.

44. A method of removing the effects of background and dark current from a signal generated from a gated reflection of a pulsed source of light reflected from an object, the method comprising;

generating a value based on gating a reflection of a pulsed source of light reflected from an object;

generating a second value based on gating when no reflected light is present; and

subtracting the values to form a corrected values.

45. A method according to claim 44 wherein the gating of the reflection of the pulsed source is so timed and of such a duration that only a portion of the light from the source reflected from the object is utilized in generating the value.

46. A method according to claim 44 wherein the gating of the reflection of the pulsed source is so timed and of such a duration that all of the light from the source reflected from the object is utilized in generating the value, such that the value is a normalizing value.

47. A method of removing the effects of background and dark current from a signal generated from a gated reflection of a pulsed source of light reflected from an object and normalizing the signal, the method comprising;

providing a value generated in accordance with claim 45;

providing a normalizing value generated in accordance with claim 46; and

normalizing the value generated in accordance with claim 45 utilizing the normalizing value.

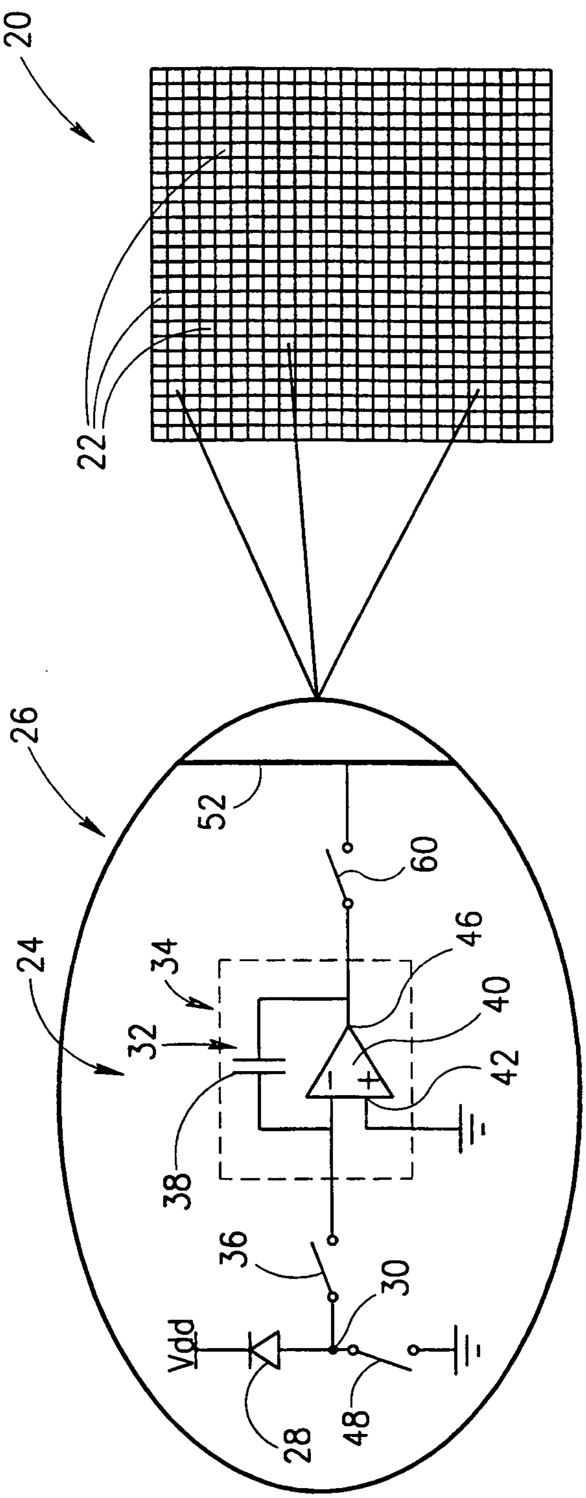


FIG.1A

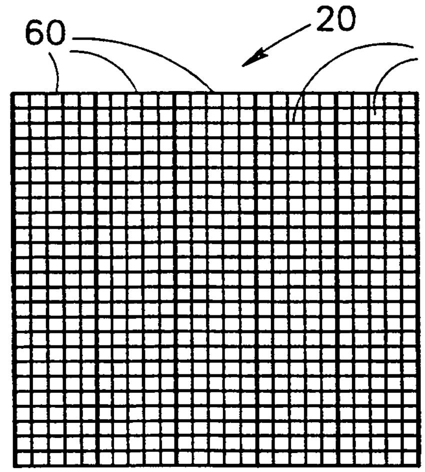


FIG.1B

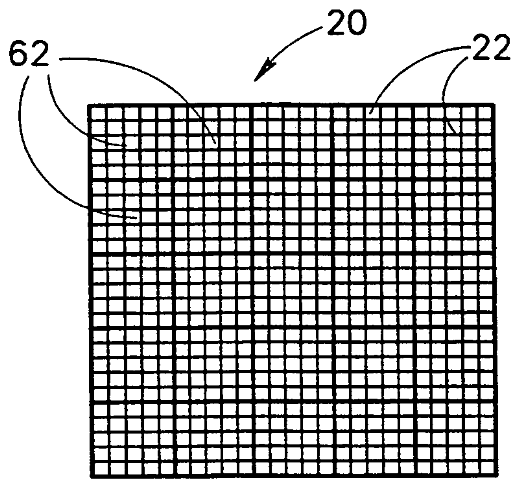


FIG.1C

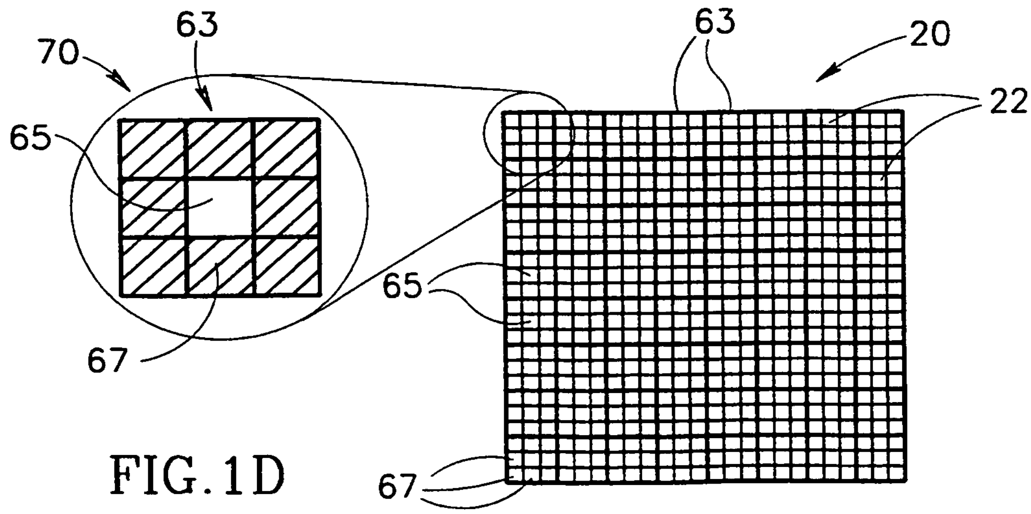


FIG.1D

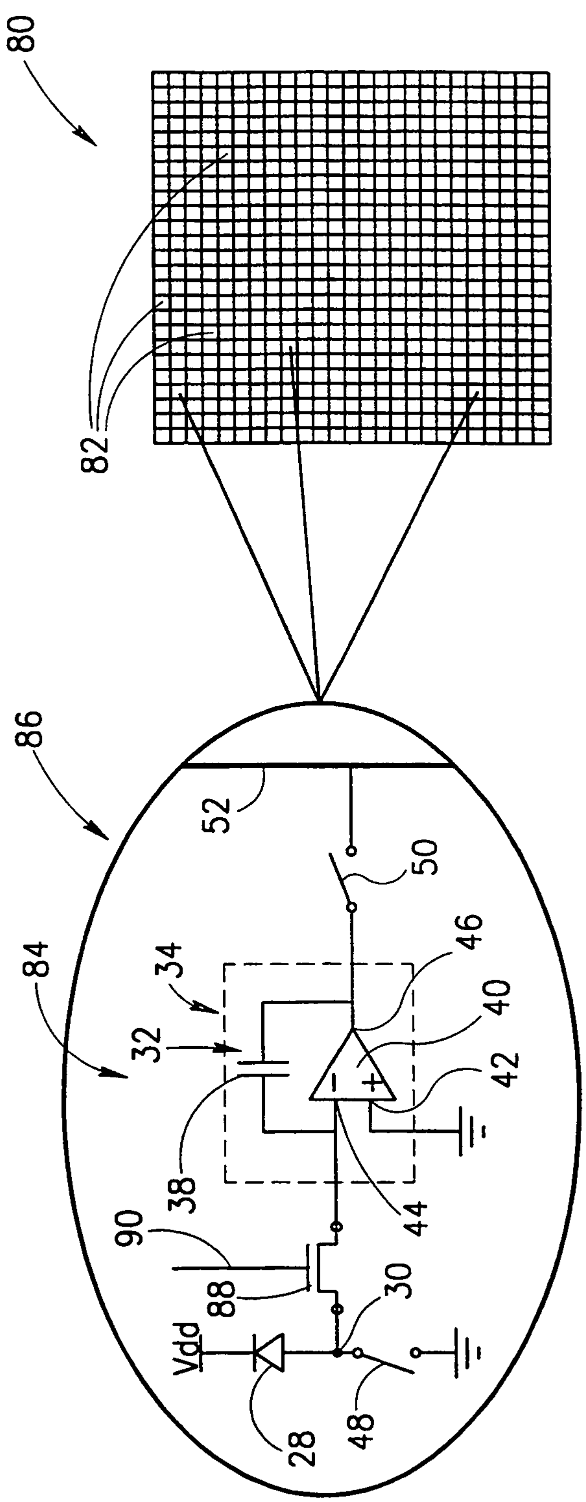
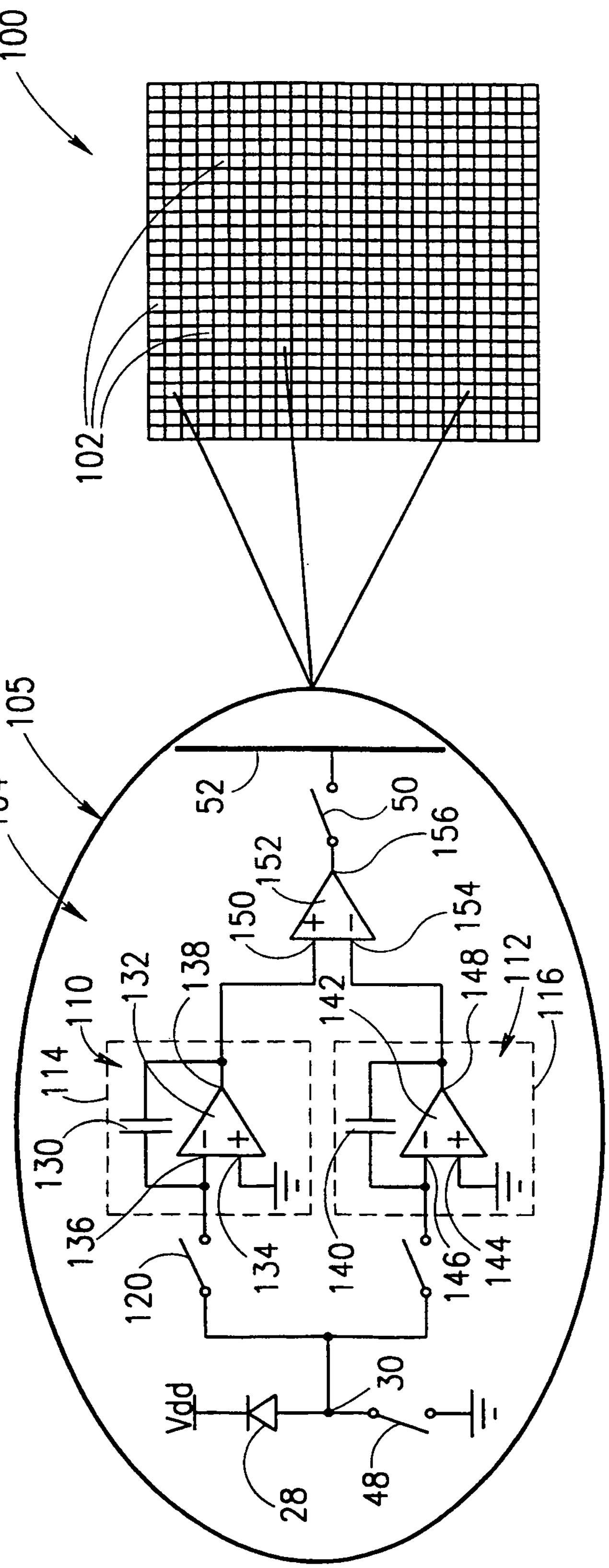


FIG.2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150
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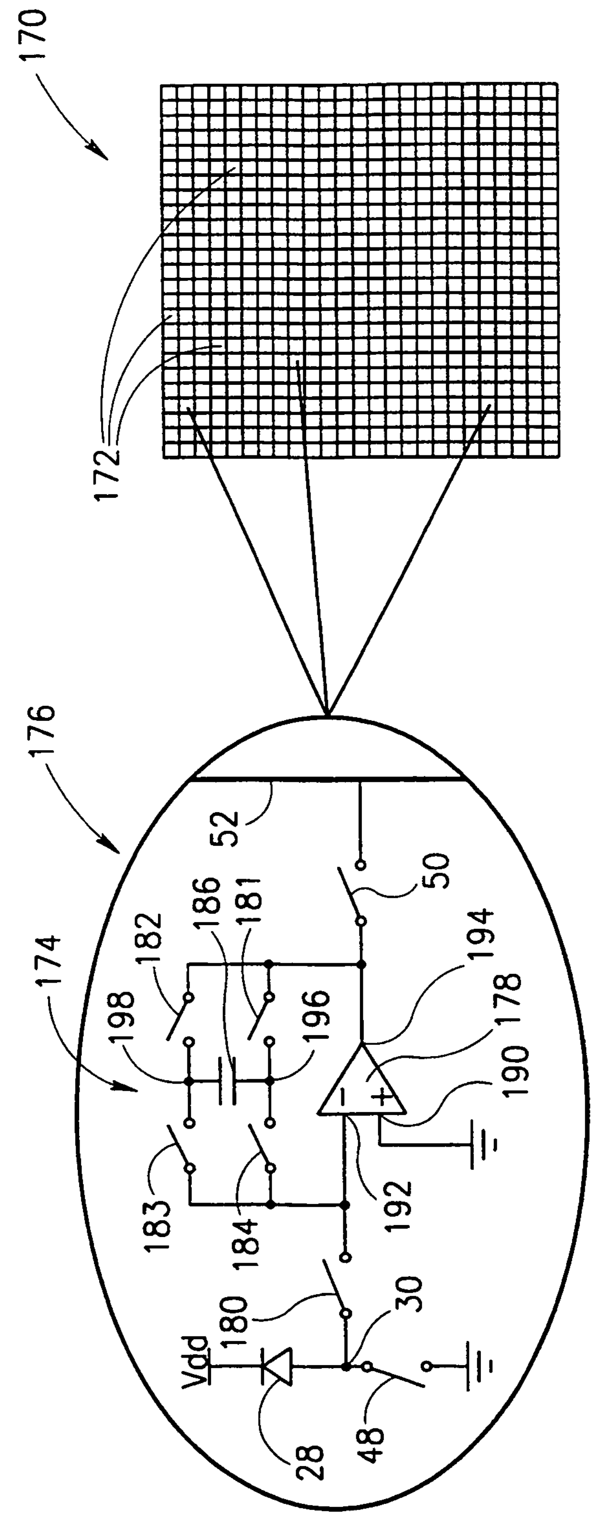
142
148
112
116
140
146
144
30
Vdd
28
48

FIG.3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Vdd
28
48

FIG.4

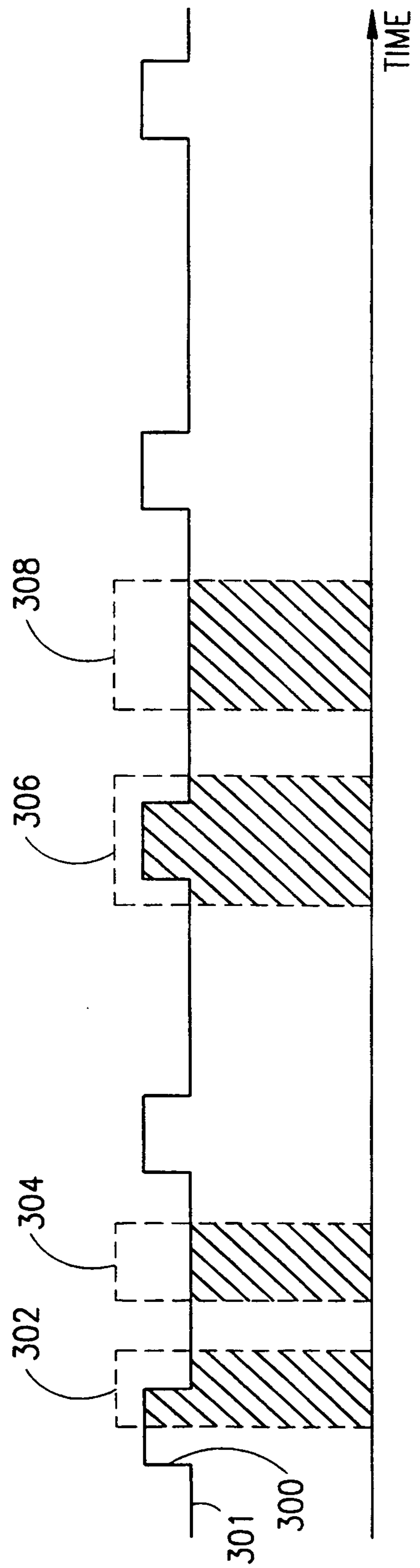

FIG.5

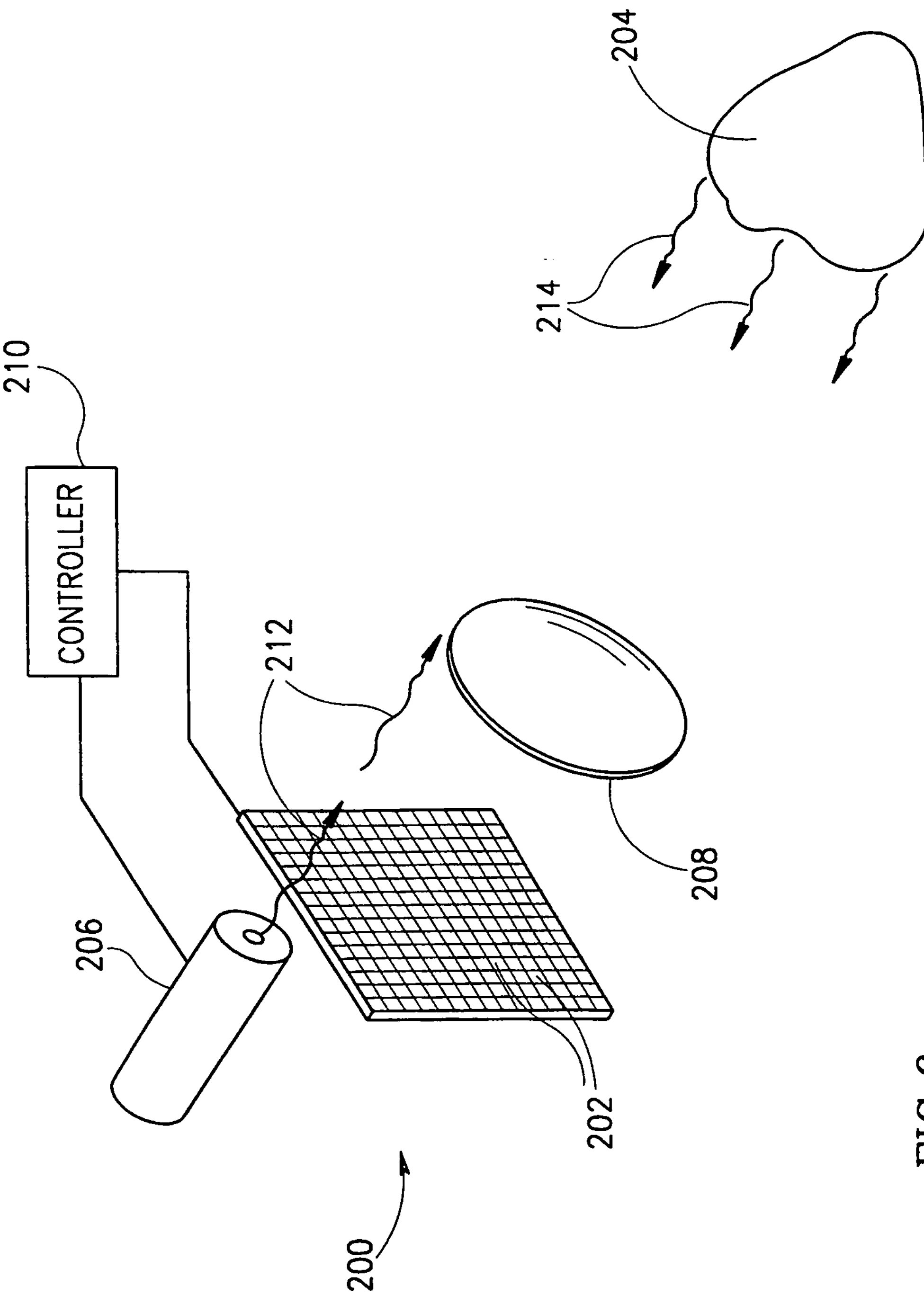

FIG.6

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 98/00476

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04N3/15 G01S17/08 H04N5/217

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04N G01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 28558 A (FOSSUM ERIC R ;CALIFORNIA INST OF TECHN (US)) 7 August 1997 see page 7, line 3 - page 8, line 8 see page 11, line 13 - page 15, line 20; figure 3A	1-15,44
X	US 5 329 312 A (BOISVERT DAVID M ET AL) 12 July 1994 see figure 2	1-15
X	US 5 488 415 A (UNO MASAYUKI) 30 January 1996 see figure 18 see column 12, line 11 - line 63; figures 13,14	1-7,16, 17,19,20

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 May 1999	25/05/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	De Paepe, W

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IL 98/00476

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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			AU	1835397	A	22-08-1997
			EP	0878007	A	18-11-1998
			WO	9728641	A	07-08-1997
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